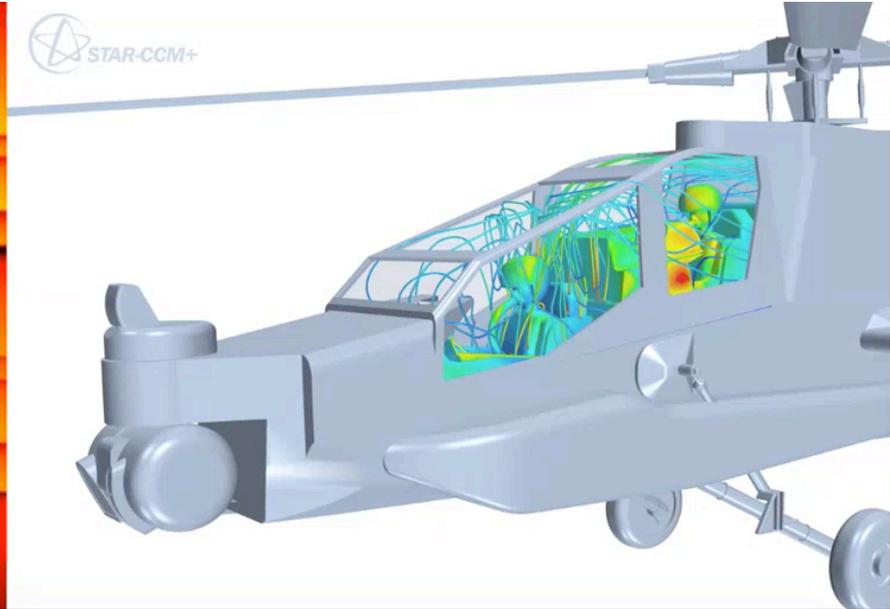
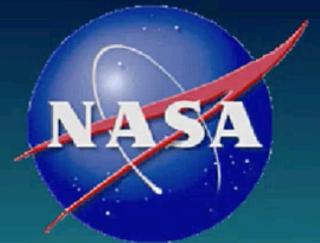


STAR-CCM+



Advanced Modeling and Simulation Symposium Series

NASA Ames Research Center
February 11th 2021



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The Impact of Multi-Physics CFD Simulation in Aircraft Safety and Droplet Modeling

Dr. Durrell Rittenberg, Director of Aerospace and Defense Siemens DISW Simcenter

Prashanth Shankara, Sr. Product Marketing Manager

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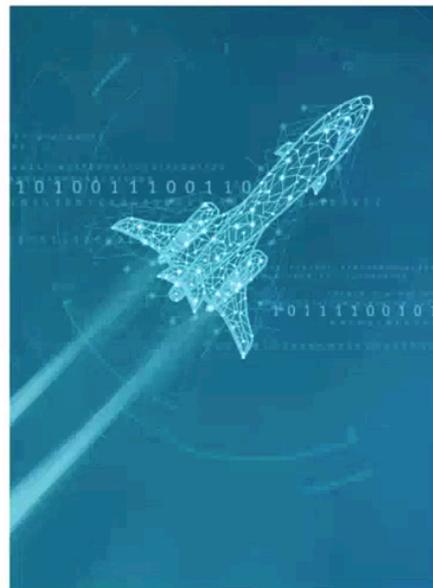
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Key Trends Aerospace and Defense

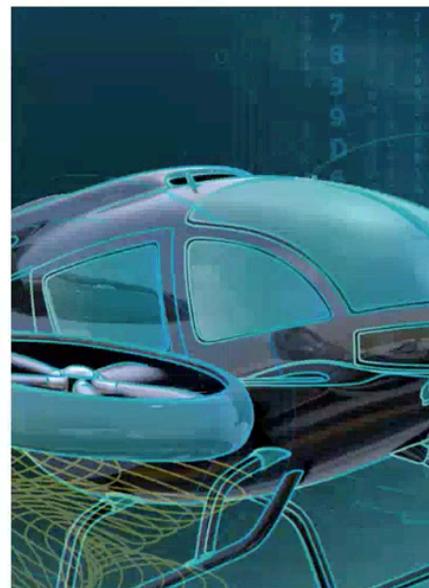
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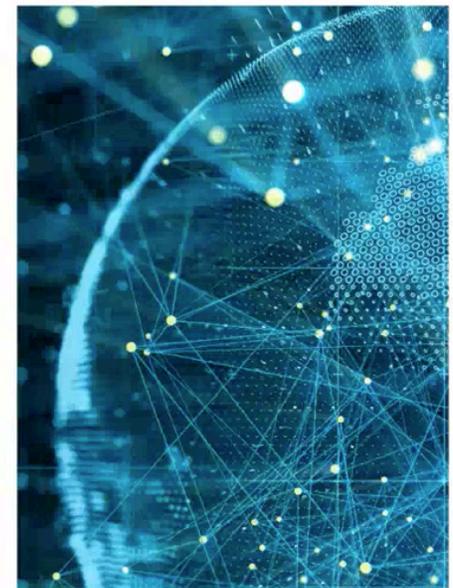
**Pressure to Reduce
Program Cost and
Schedule**



**Increasing Program
Complexity and
Integration**

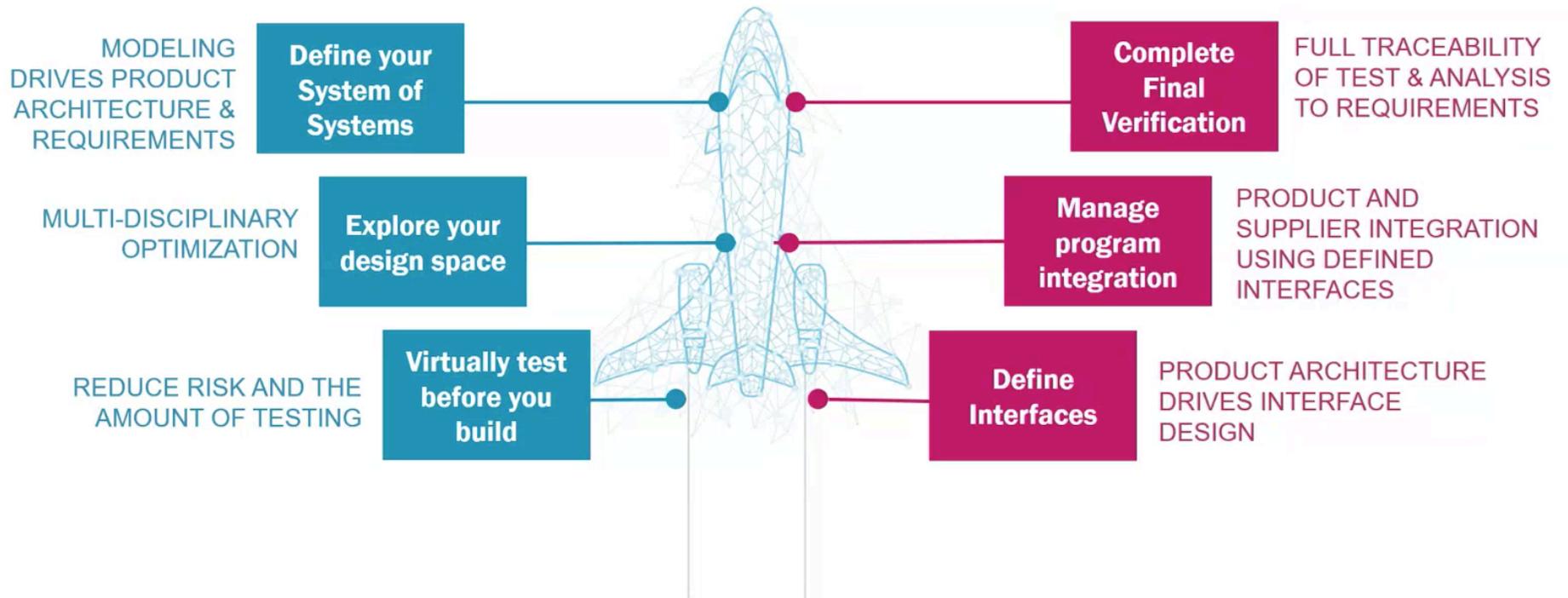


**Increased
Electrification
of Products**



Globalization

Digital Thread – Improving Program Execution



Simcenter for Aerospace Systems Performance Engineering

Scalable Solutions to address Mission Critical Development



Integrated Performance

Sub-System Performance

Component Performance

Domains

Digital Twins / Physics

Lifecycle & Digital Thread

Program Execution Excellence
Value Streams

Integrated
System
Performance

ELEC &
Avionics

Propulsion
Systems

Airframe

HYDR,
LG & FCS

ECS
& AIR

FUEL

CFD

System Sim.

3D

Software

TEST

Concept

Detailed

Verification

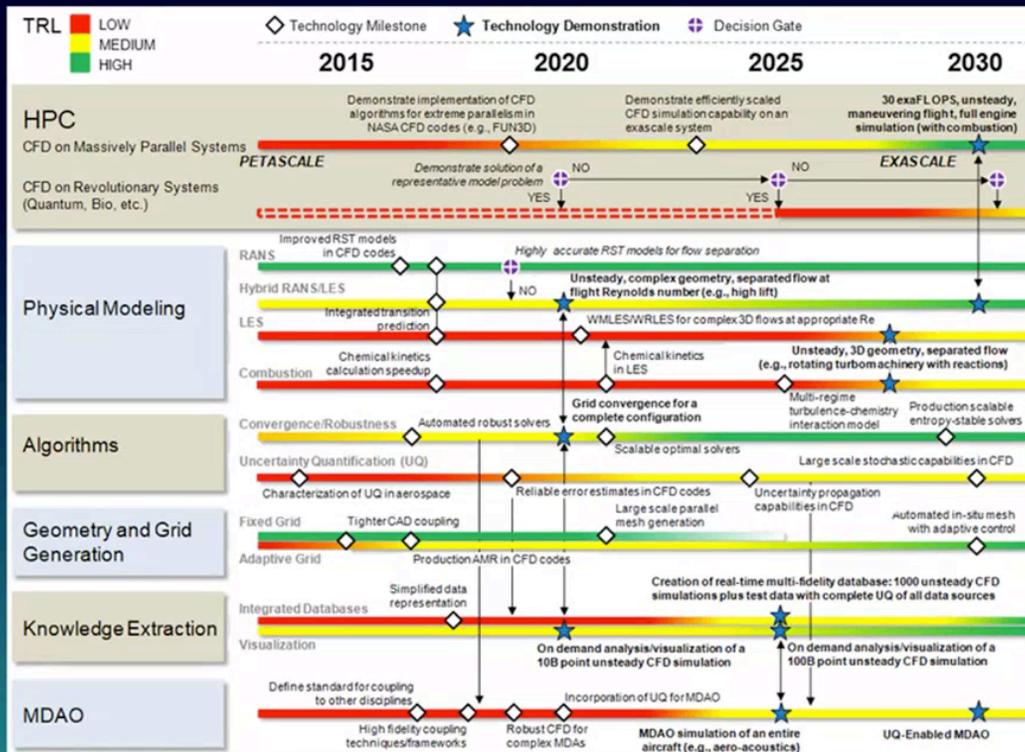
In Service

MBSE

Design & Engineering

Verification Management

Siemens Simcenter supporting AIAA and the broader community



- CFD 2030 guiding our development direction and priorities
- AIAA Workshops
 - DPW, HLPW, PAW, WIPP
 - Transition Modeling
 - Hover prediction
 - Sonic Boom
- Committees
 - EATS
 - IPW (ASME)
 - INPSI
- Research programs
 - Clean Skies (1, 2, 3)
 - LUFO
 - Multiple SBIR (corrosion)

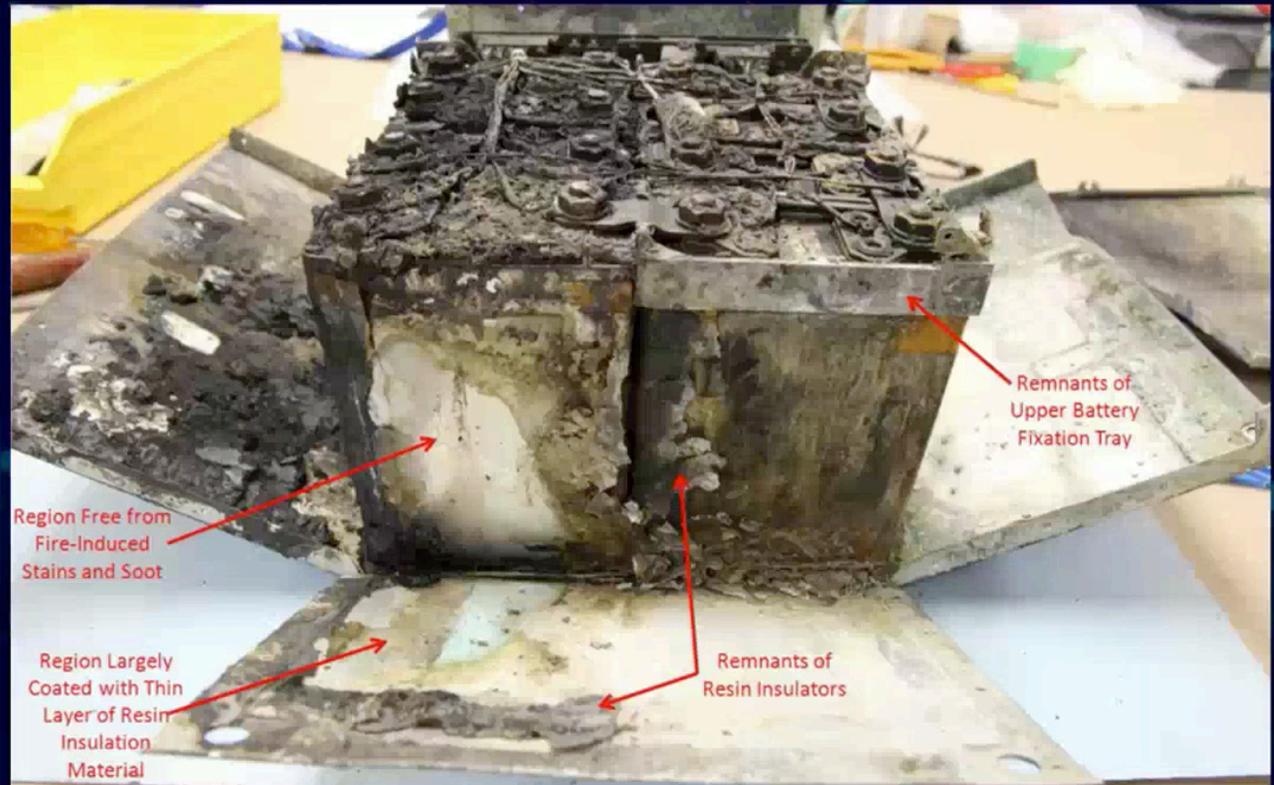
Multiphysics simulation for Battery safety

Challenge

- Ensure safe containment during thermal runaway – failure in one cell propagates.
- Regulation en route. Key for brand.
- Complex multiphysics problem (multiphase, reactions, thermal radiation, FSI, phase change, ...)

Solution

- Multiphysics prediction cell failure and runaway used to design containment strategy.



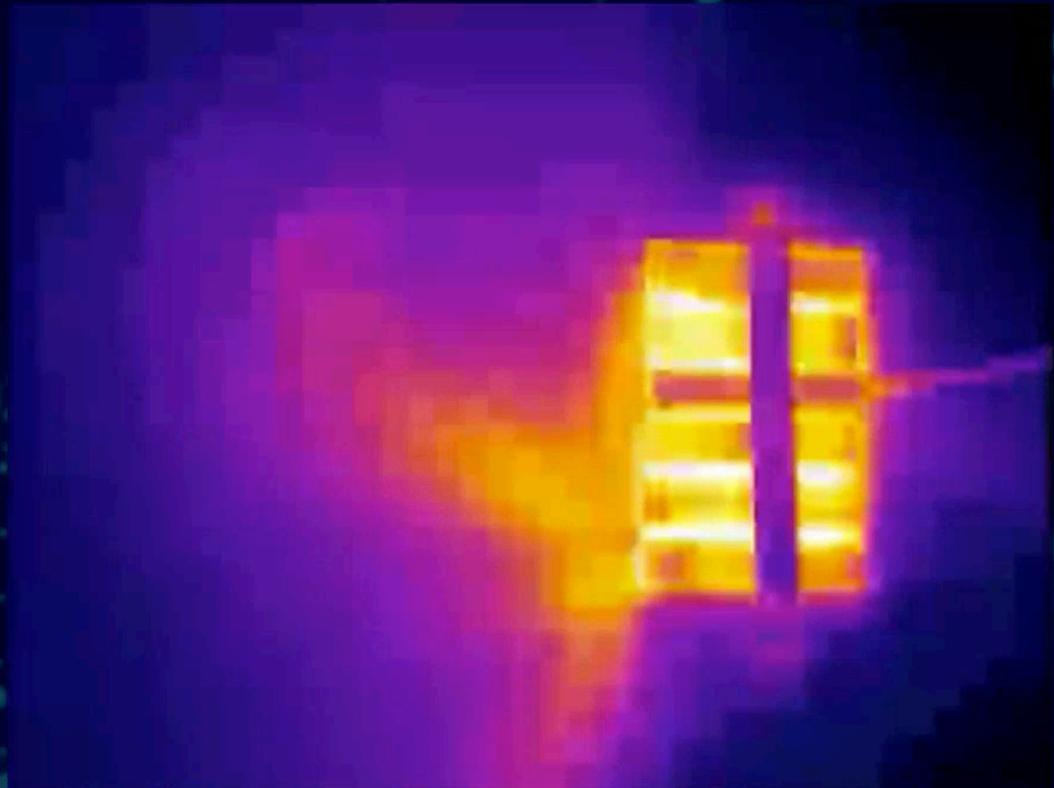
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Cold weather flight in UAM

Challenge

- Impact of energy use
- Avoiding ice formation
- Sensor location planning
- Design of protection systems

Solution

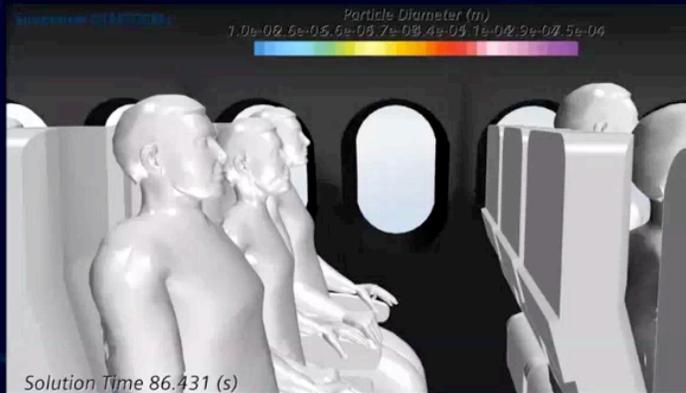
- Multi-phase predictions of real world conditions?
- Understanding heat transfer
- Ice formation and aerodynamic performance



Safe cabin environments

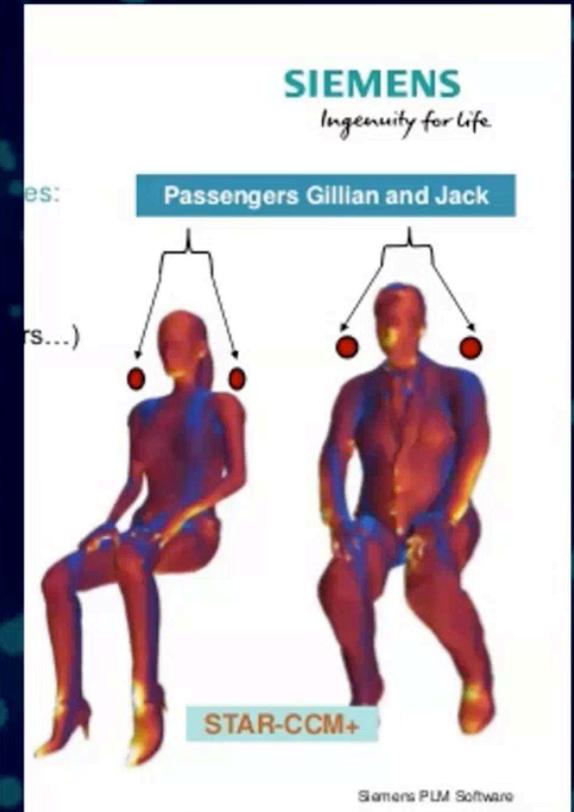
Challenge

- Design ECS systems to ensure comfort and safety
- Certify airflow and filtration
- Certify seat design
- Reduce unwanted noise



Solution

- Multiphase simulation and droplet simulations
- Acoustic testing and simulation
- Thermal comfort models for cabin design



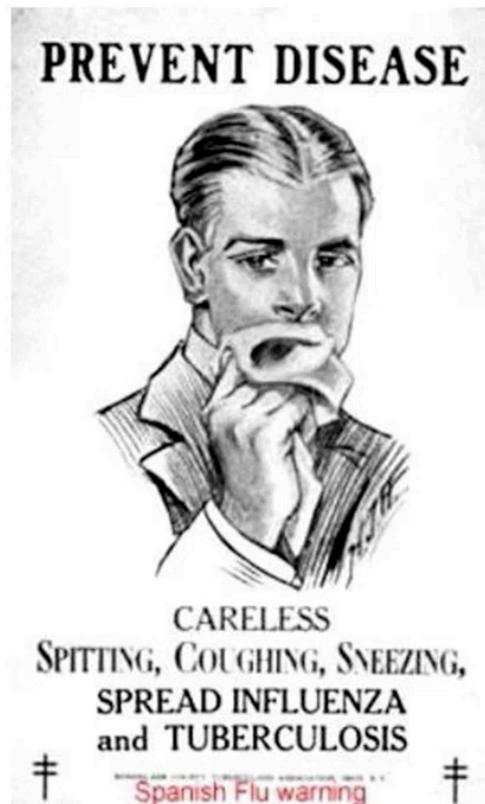
High-fidelity cough simulation in an aircraft cabin

Prashanth Shankara – Siemens Digital Industries Software



The human cough

Source of transmission for airborne infections



Coronavirus Disease 2019

COVER YOUR COUGH

PREVENT PEOPLE AROUND YOU FROM GETTING SICK



Cover your mouth and nose with a tissue when coughing or sneezing.
Put your used tissue in a waste basket and wash your hands or use an alcohol-based gel.



If you don't have a tissue, cough or sneeze into your upper sleeve, not your hands.



If you are sick and face masks are available, use one to protect others.

The human cough

Source of transmission for airborne infections

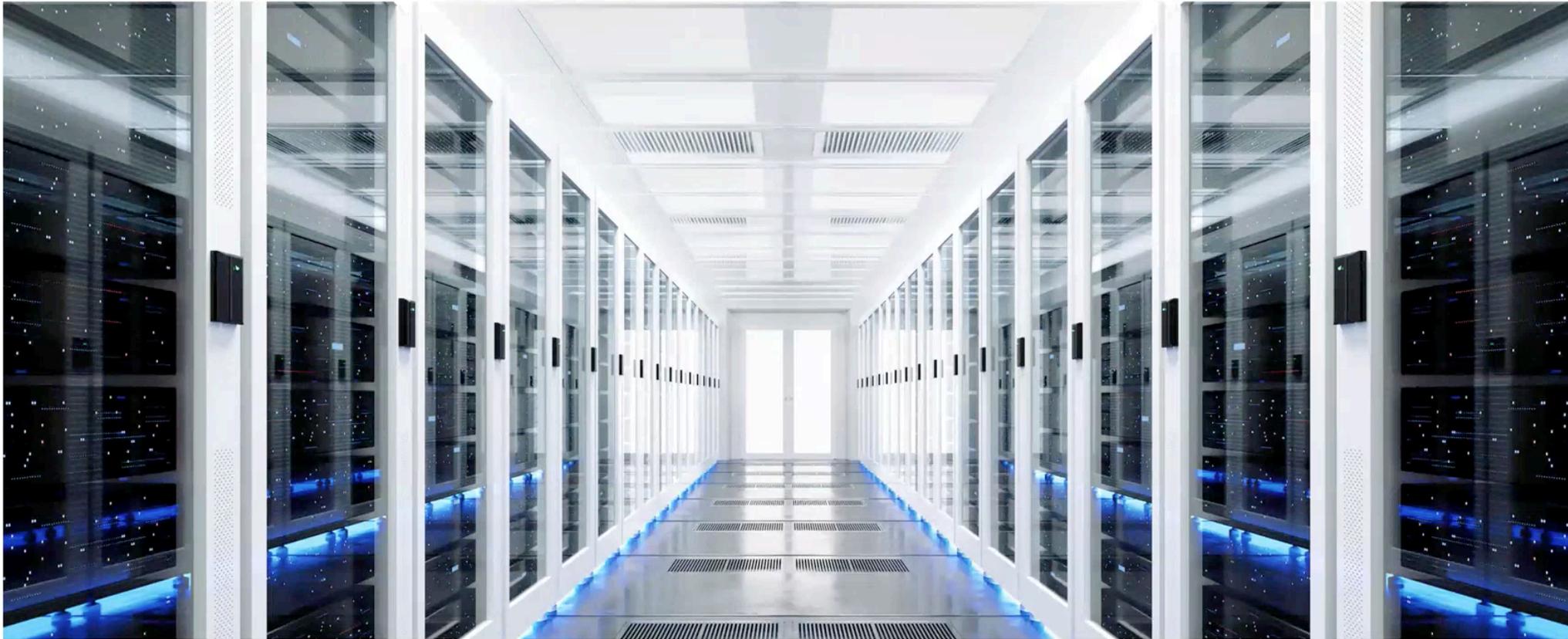


The screenshot shows a Google search interface. The search bar contains the text "airborne infection transmission". Below the search bar, navigation links for "All", "Shopping", "News", "Videos", "Maps", and "More" are visible, along with "Settings" and "Tools". A red box highlights the search result summary: "About 6,640,000 results (0.51 seconds)". Below this, a search result from "www.cdc.gov" is shown, titled "Scientific Brief: SARS-CoV-2 and Potential Airborne ... - CDC", dated "Oct 5, 2020". The snippet reads: "Most infections are spread through close contact, not airborne transmission. ... Droplet transmission is infection spread through exposure to ...". Below the search results is a "COVID-19 alert" section titled "Common questions" with four expandable items: "What is the difference between airborne and droplet transmission?", "Is the coronavirus disease transmission airborne?", "What does airborne transmission mean?", and "How far can the virus that causes COVID-19 travel in the air?". A "Feedback" link is located at the bottom right of the alert section.

The human cough

Source of transmission for airborne infections

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Page 3

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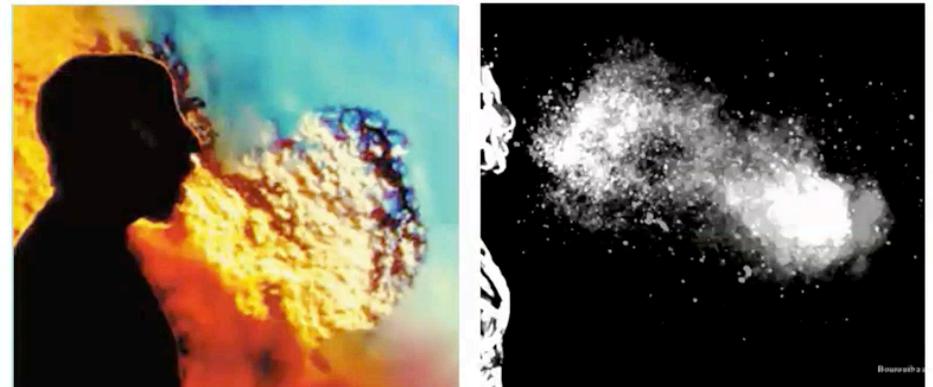
The human cough

Source of transmission for airborne infections

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Understanding the human cough is critical to evaluating transmission risk



The human cough

Source of transmission for airborne infections



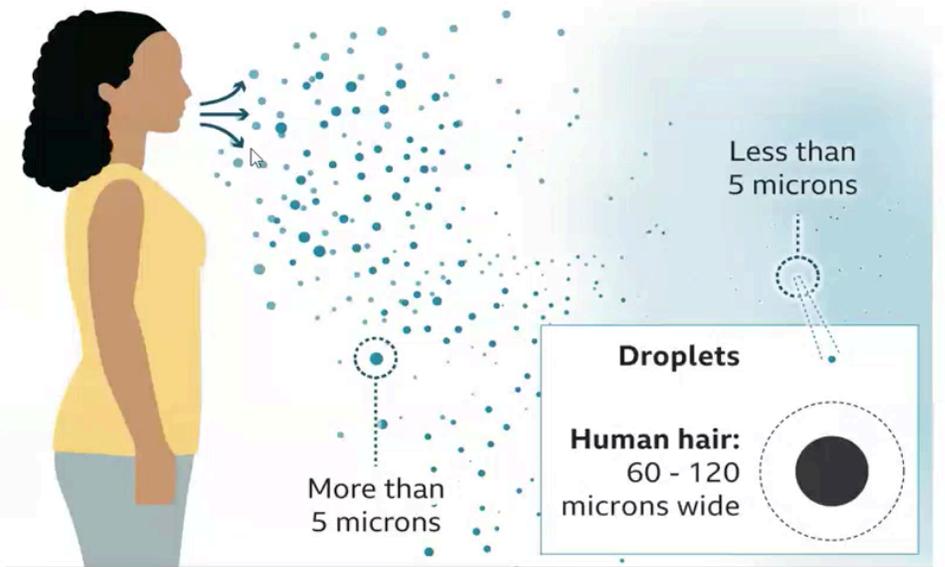
The difference between droplet and airborne transmission

Droplet transmission

Coughs and sneezes can spread droplets of saliva and mucus

Airborne transmission

Tiny particles, possibly produced by talking, are suspended in the air for longer and travel further

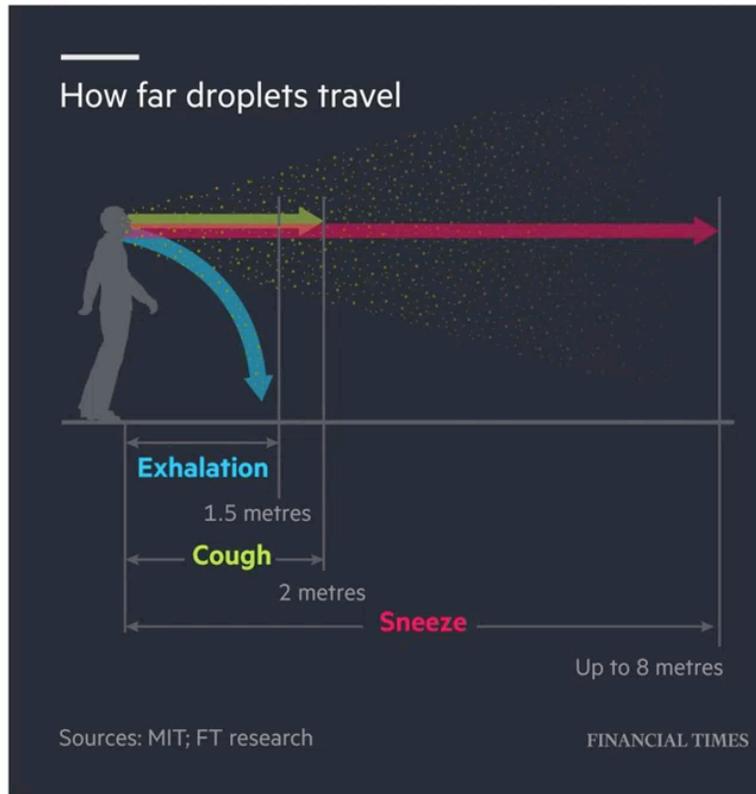


Source: WHO

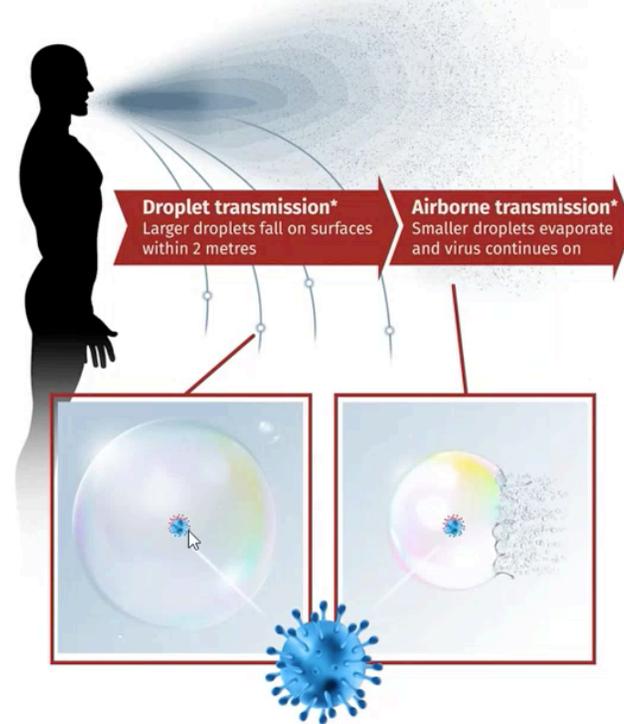


How far do cough droplets travel?

Source of transmission for airborne infections



What happens at two metres when someone coughs?

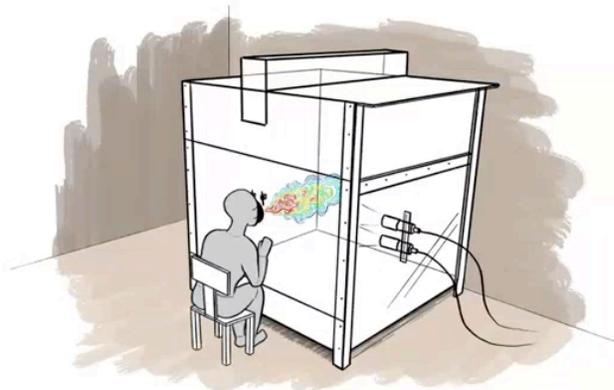


*Not to scale. Coronaviruses are 120-160 nm (less than 0.0002 mm) in diameter.

Designing safer indoor environments

Test vs simulation (1 vs 100 design scenarios)

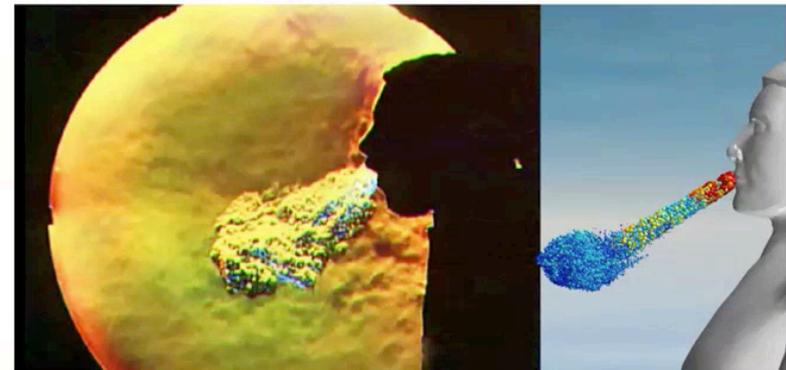
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Source: Western University



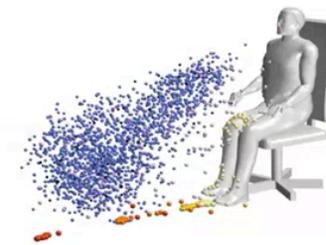
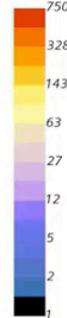
Source: NIOSH



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Solution Time 9.75.

Particle Diameter (um)



Transport from an infected person

What affects the droplets and where they go?

Indoor/outdoor

Temperature/Humidity

Air flow in space

Mouth opening

And more variables....

Where does a cough go?

Coughs, along with sneezes, play a key role in transferring respiratory diseases

Can travel as fast as **80 km/h** and expel almost **3,000 droplets**

The direct jet can spray droplets **around 1.8 m**

Lighter drops can **remain airborne** and travel further

Small droplets may float into **ventilation systems**

What is in a cough?

Can contain a mixture of mucus, phlegm, irritants and fluids. It can also carry **infections such as coronaviruses**

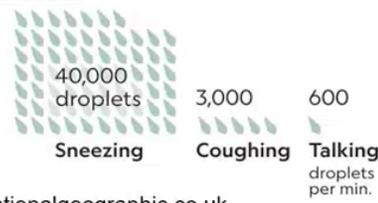
Some droplets **settle on surfaces** such as door knobs and tables

A coronavirus may remain viable on inanimate surfaces for 1 - 9 days*

Can **enter the respiratory tract of another person**

Source: MIT/Lung.org/CDC/*journalofhospitalinfection.com

© AFP



Source: www.nationalgeographic.co.uk

Transport from an infected person

What affects the droplets and where they go?

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Indoor/outdoor

Head position

Evaporation

Temperature/Humidity

Into elbow

Human heat plume

Air flow in space

Cough strength

Breathing

Mouth opening

Obstacles in space

No. of droplets

Single vs multiple

Droplet size

And more variables...

Modeling a cough with CFD simulation

The challenges

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The right approach

High-fidelity, multiphysics, simulation tool, physics involved

Droplet modeling

Method, size, distribution, angle, mouth opening

Air flow modeling

Unsteady indoor airflow modeled in CFD

Cough jet

Time dependent flow, unsteady

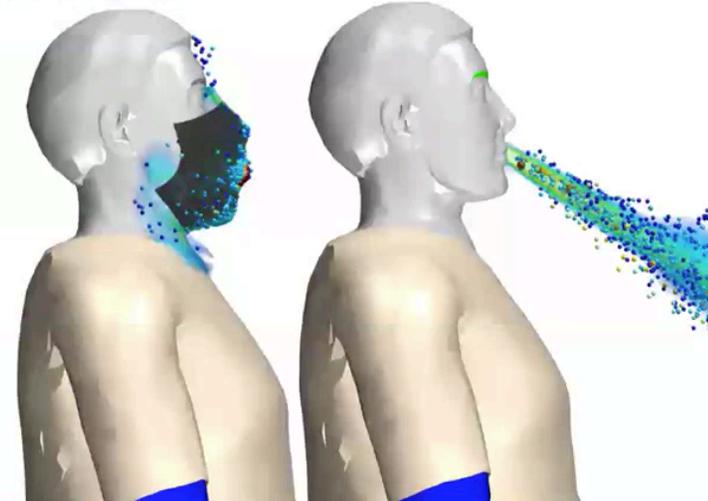
Droplet tracking

Time of tracking, evaporation, breathing, forces on droplet

Different scenarios

Flow, patient, barriers, mask, cough types

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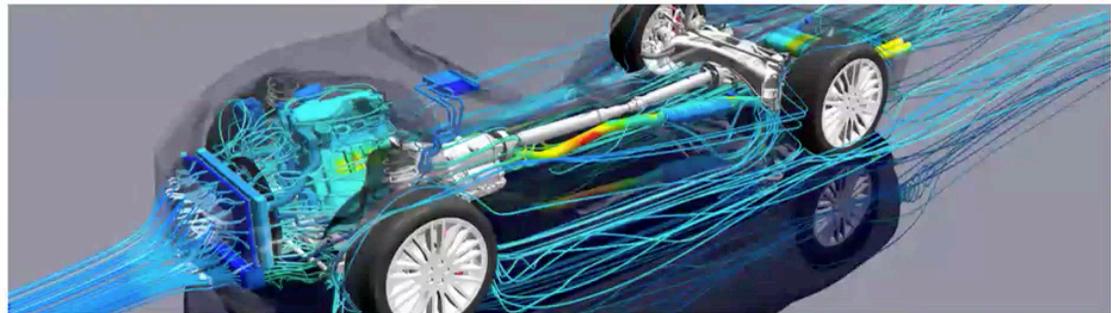
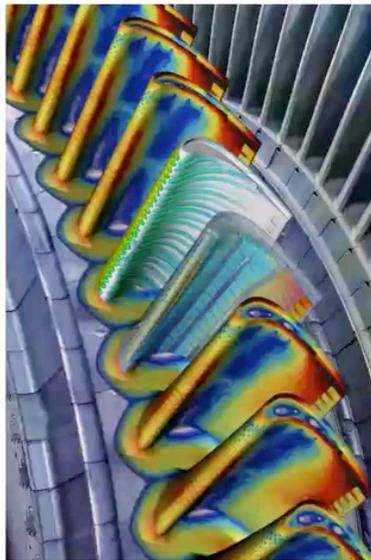
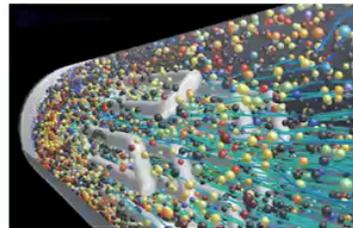
Accurately modeling a single cough is incredibly complex. All the representative physics and scenarios need to be accounted for. The exact geometry of the indoor space needs to be modeled.

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Multiphysics CFD simulation software to model cough droplets

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- Fluid dynamics
- Heat transfer
- Engine In-Cylinder
- Aeroacoustics
- Multiphase flows
- Particle flows
- Electrochemistry
- Battery Simulation
- Solid Mechanics
- Design Exploration
- Many more...



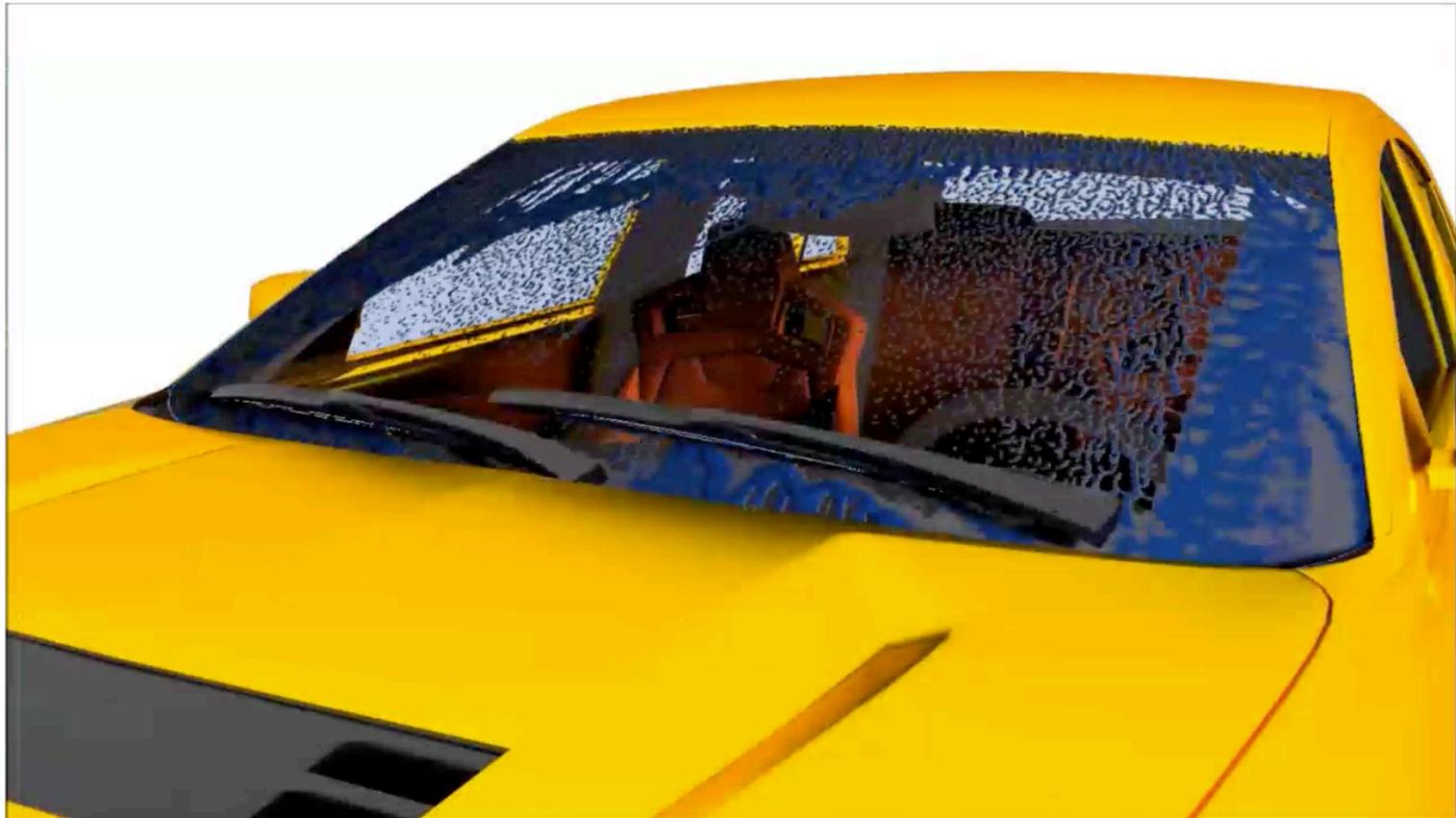
Simcenter STAR-CCM+ is the CFD-focused multiphysics engineering solution that uniquely integrates comprehensive physics with intelligent design exploration in a single CAD-to-solution environment, built for the most simple to the most advanced CFD simulation needs.

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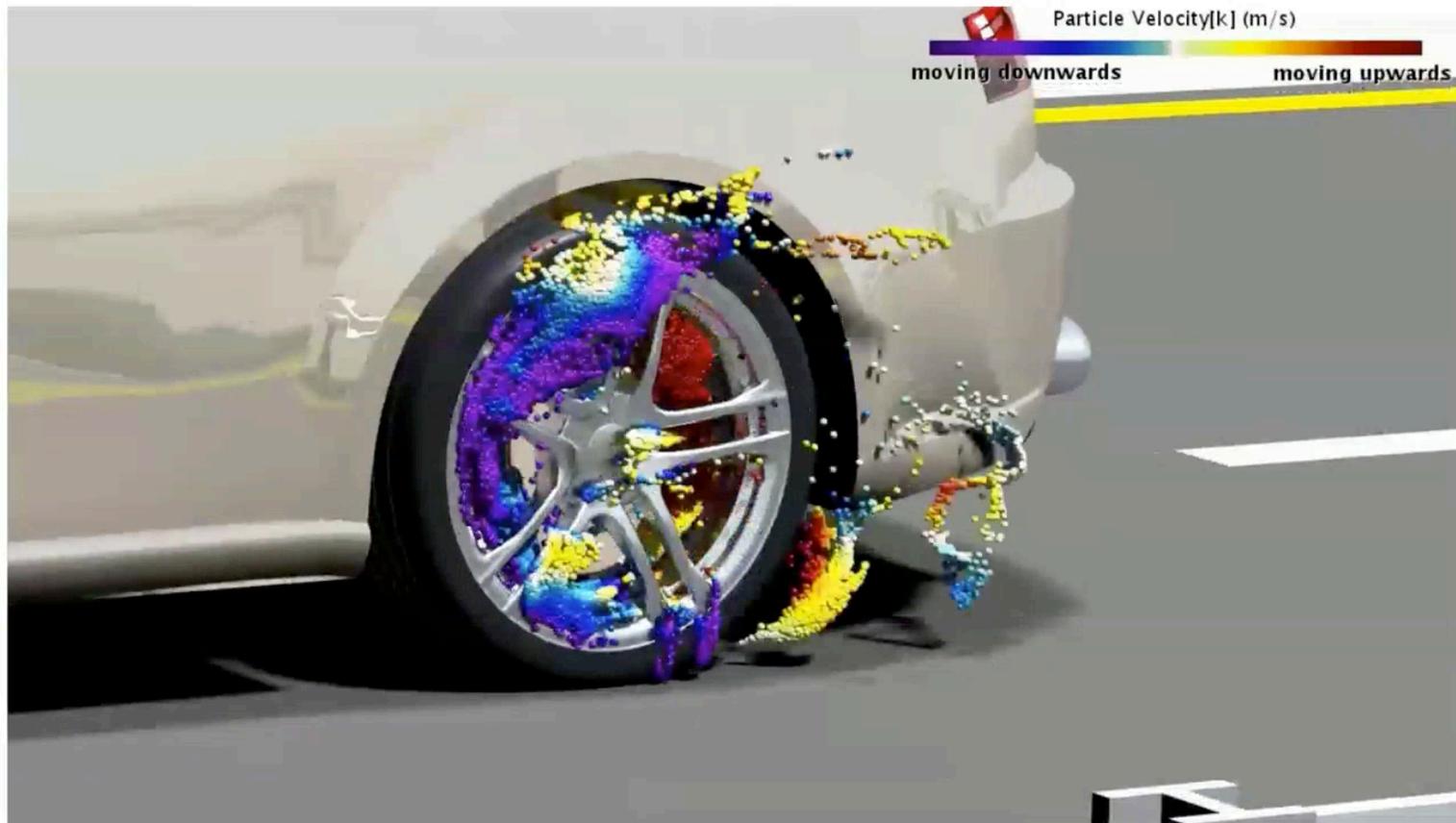


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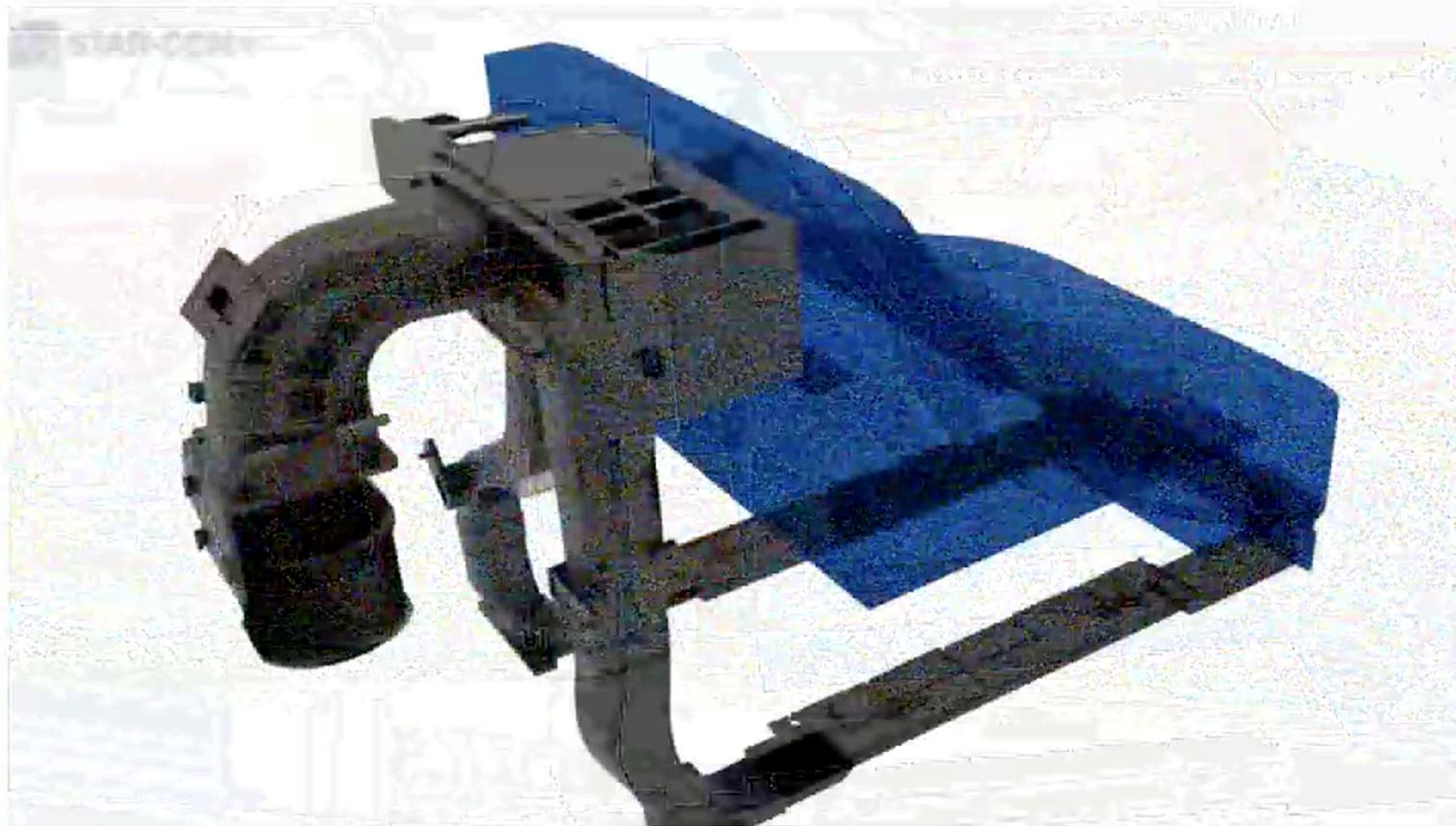


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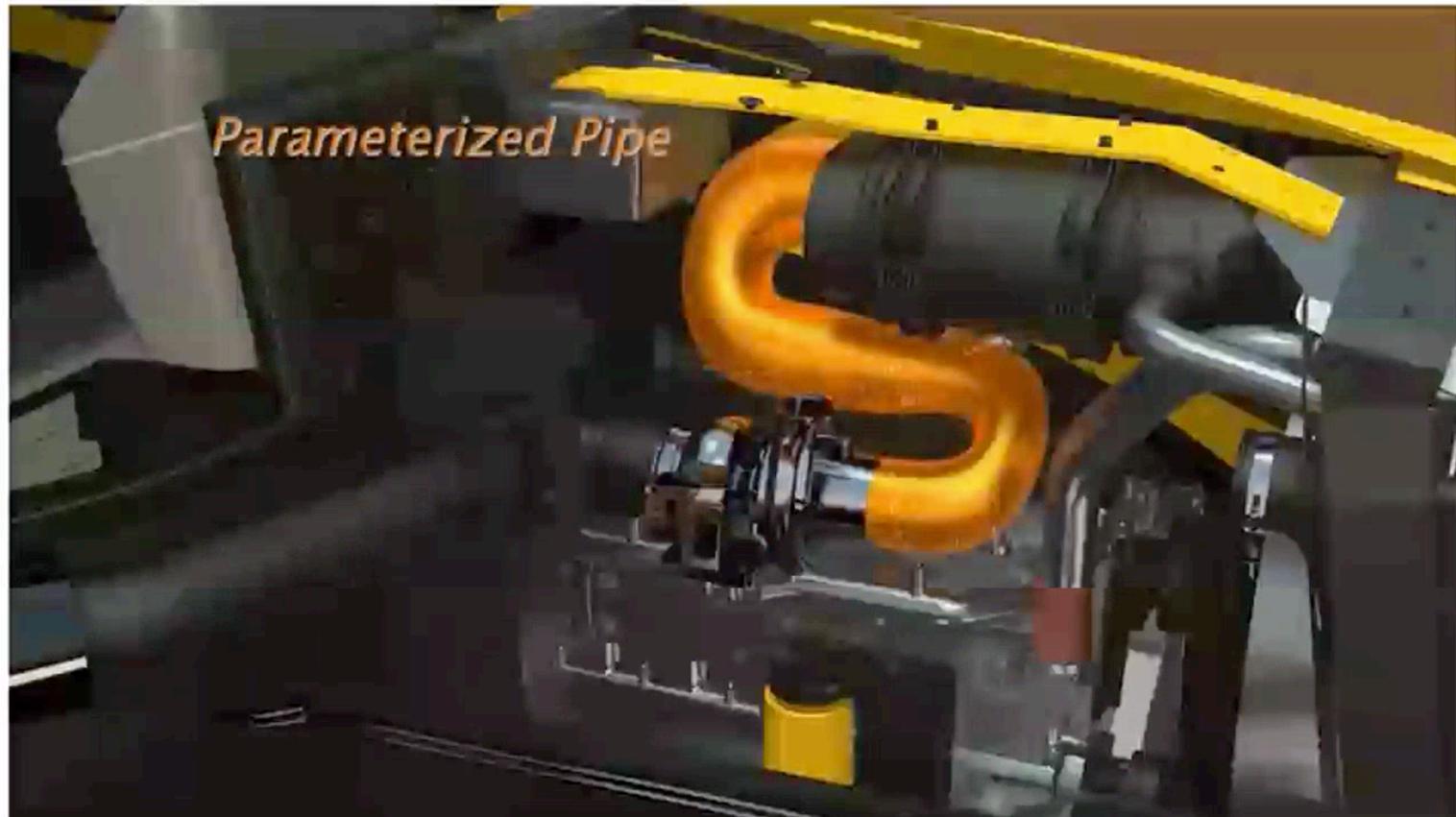


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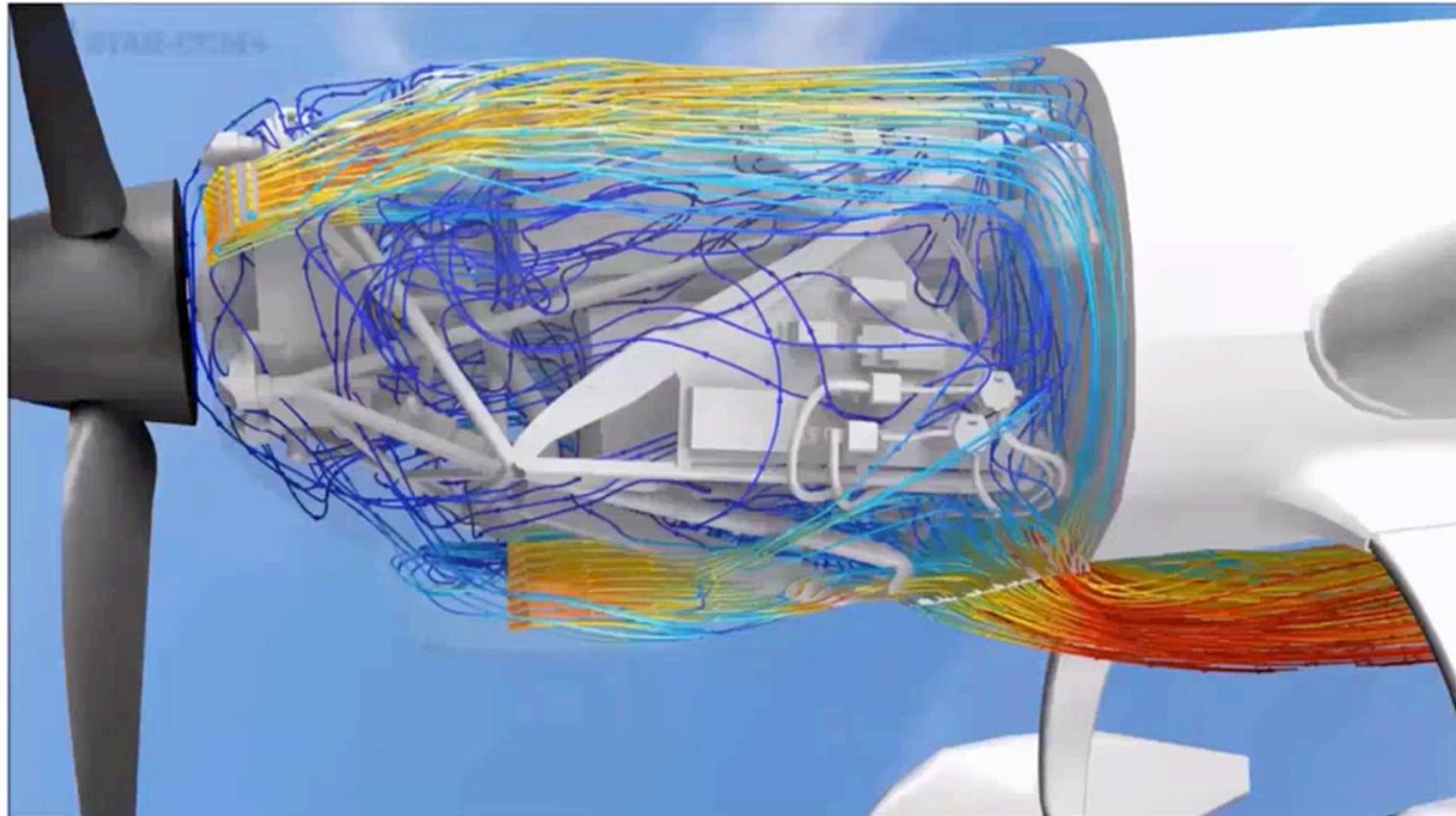


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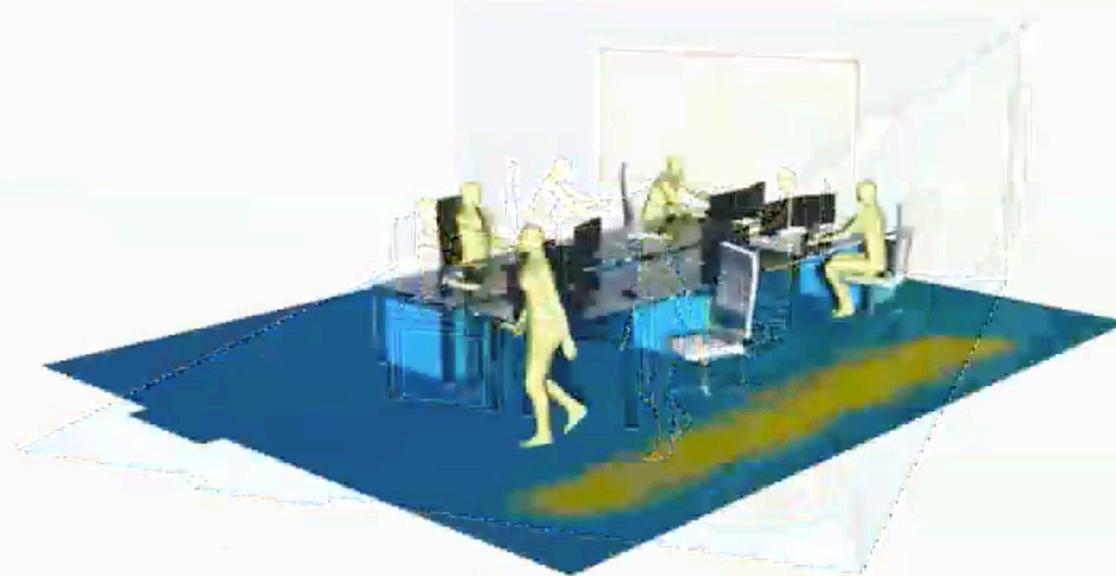
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Multiphysics CFD simulation software to model cough droplets

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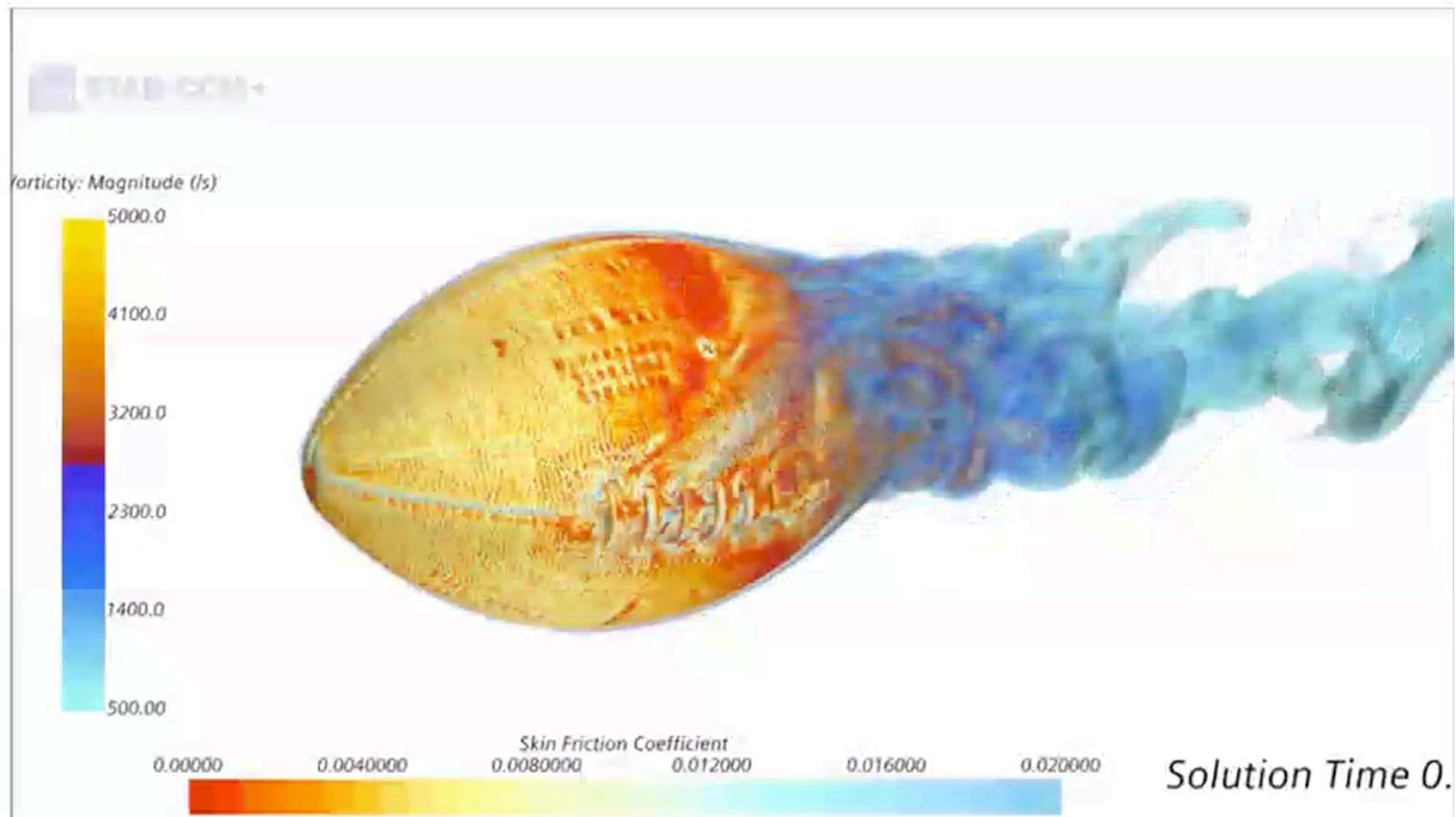


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Multiphysics CFD simulation software to model cough droplets

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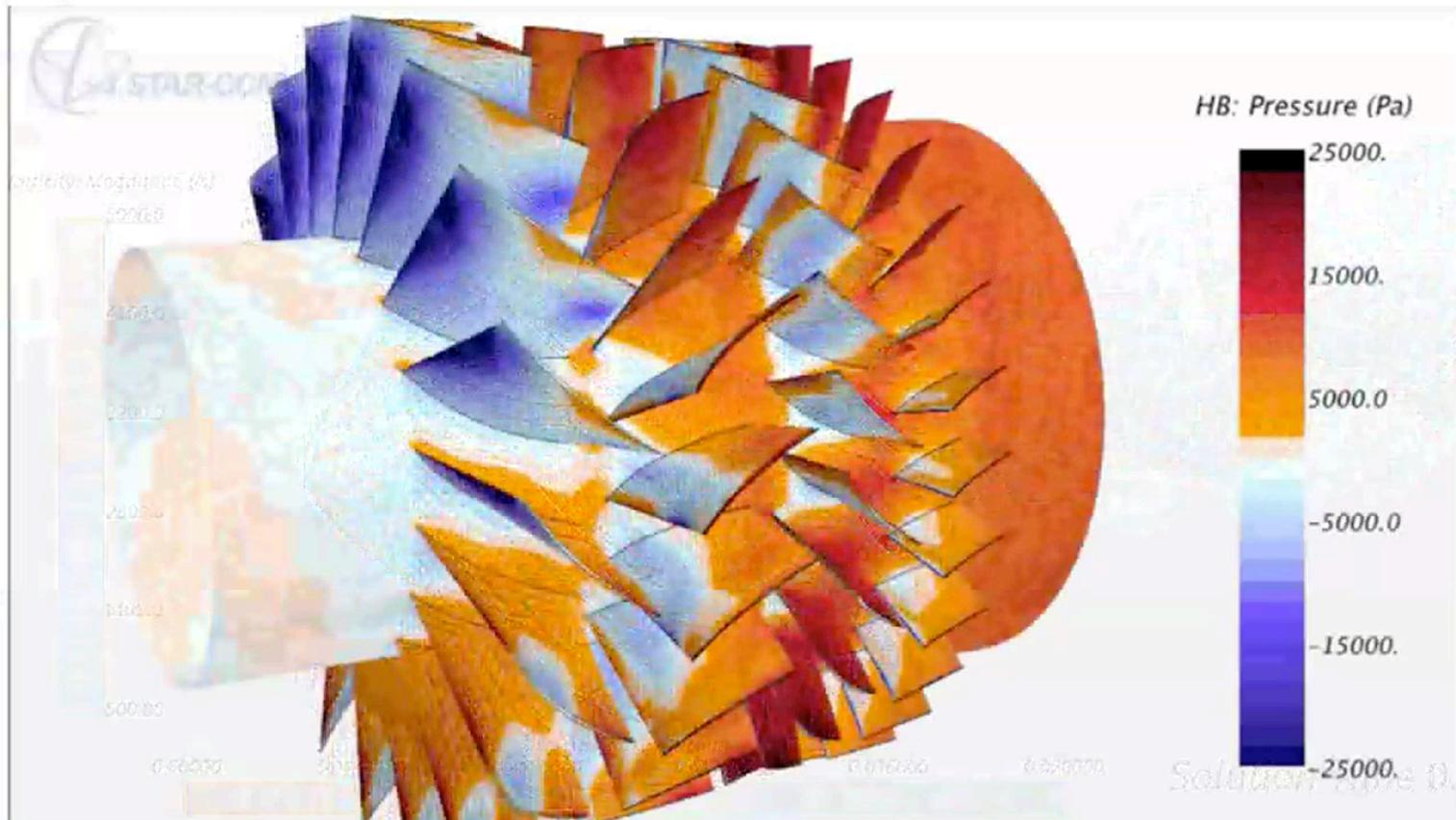


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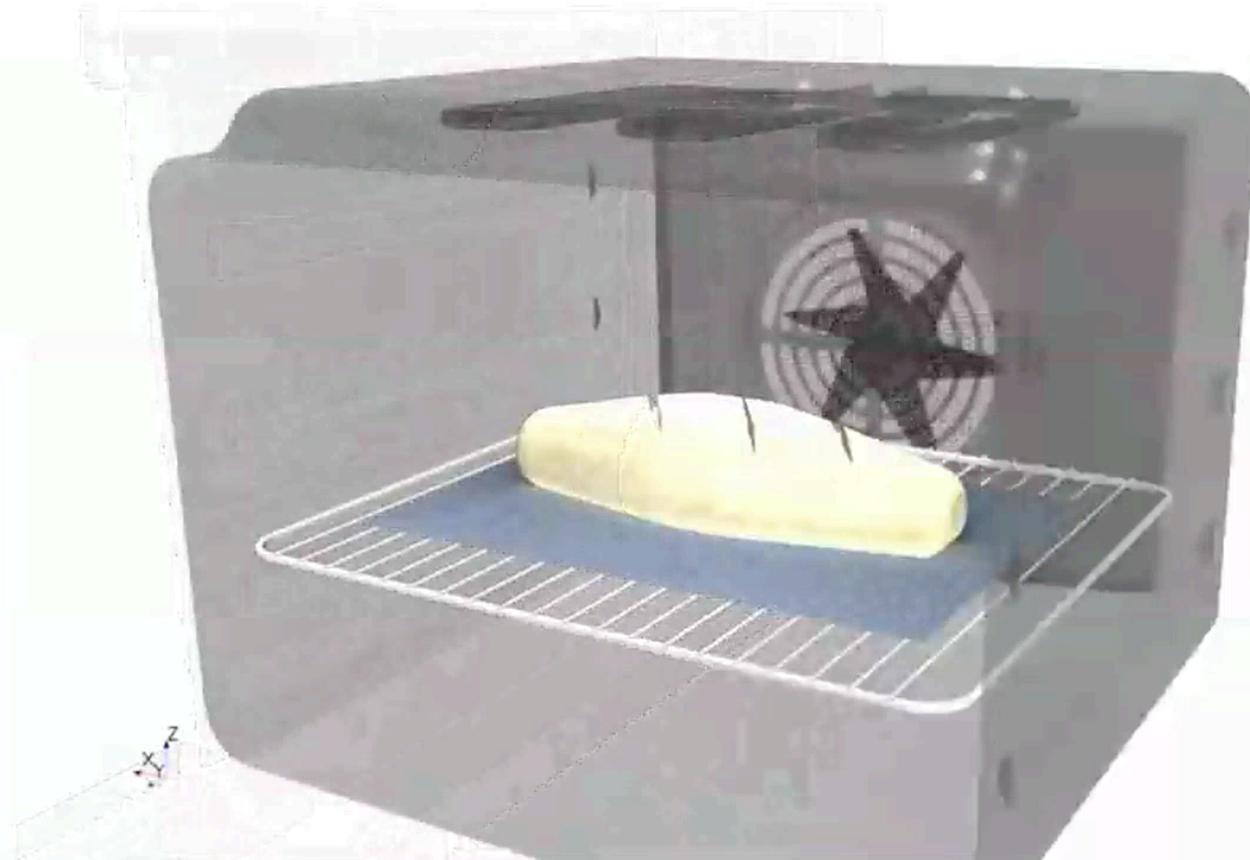


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Multiphysics CFD simulation software to model cough droplets

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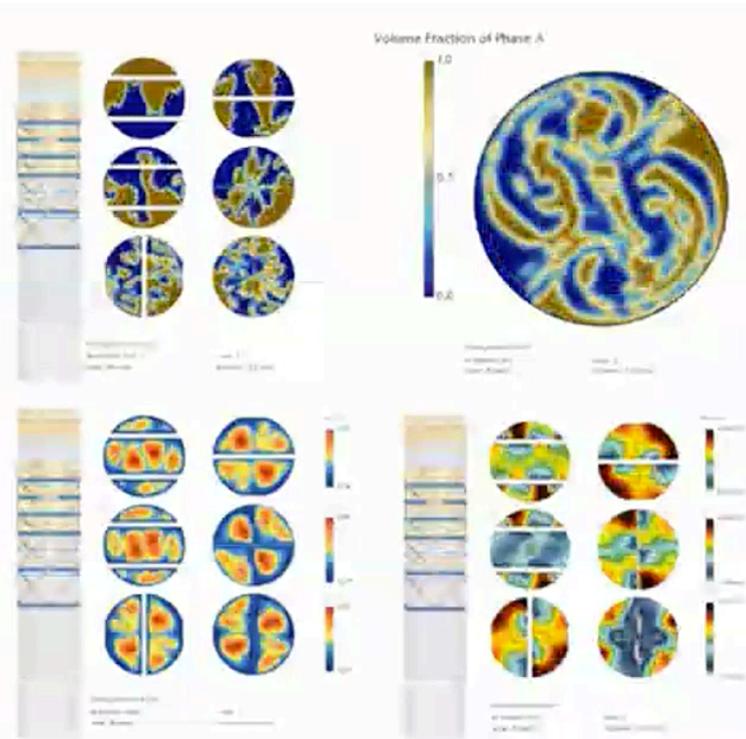
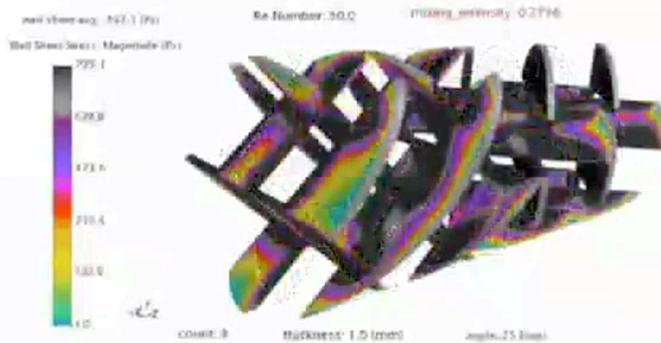
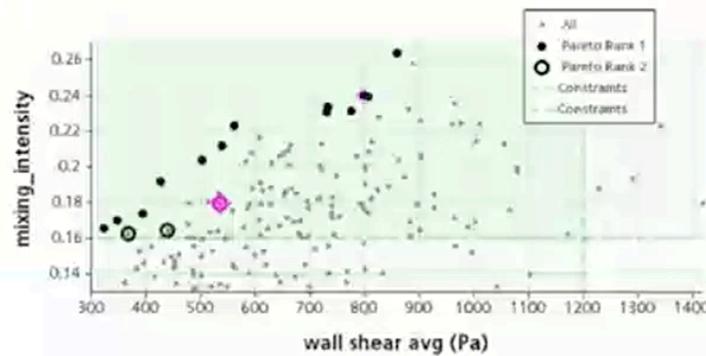


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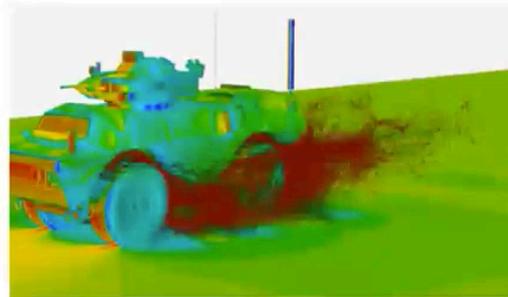
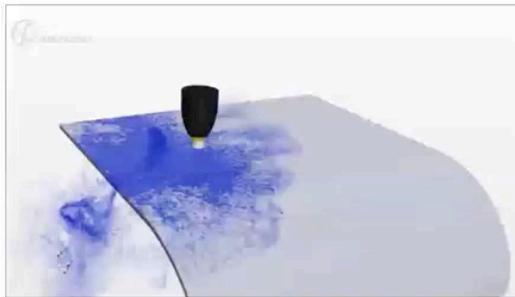
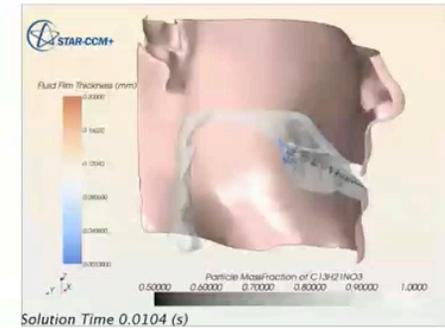
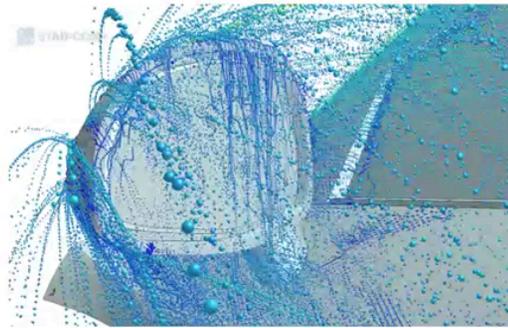
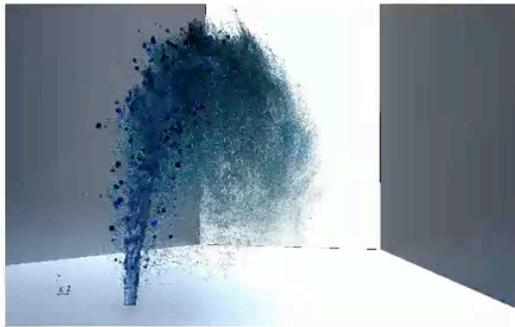


- Fluid dynamics
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Lagrangian multiphase model to simulate cough droplets



- **Lagrangian Multiphase (LMP)**

- The observer tracks parcels of particles as they move through space & time.

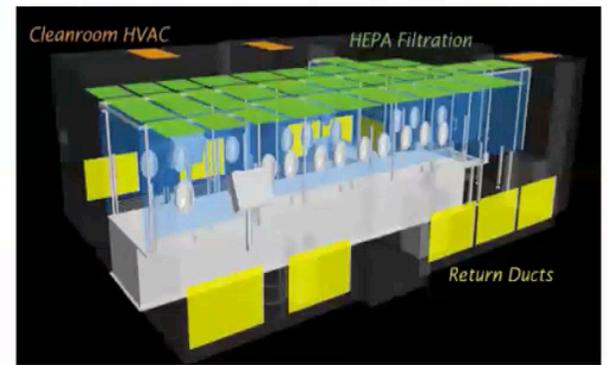
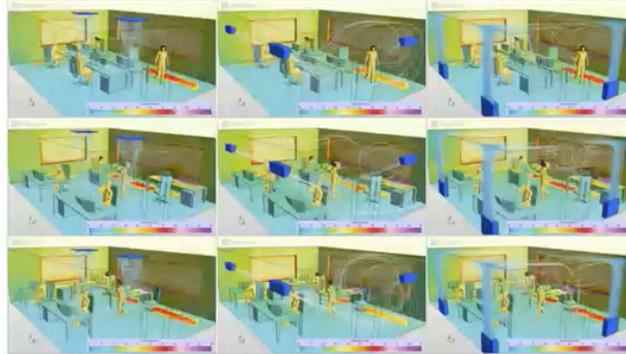
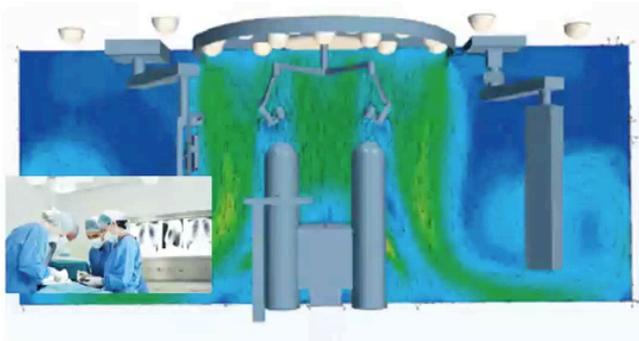


- One or two way coupled with airflow.
- Impingement model allows both bounce or stick conditions.

Simcenter STAR-CCM+ CFD simulation for ventilation and comfort studies



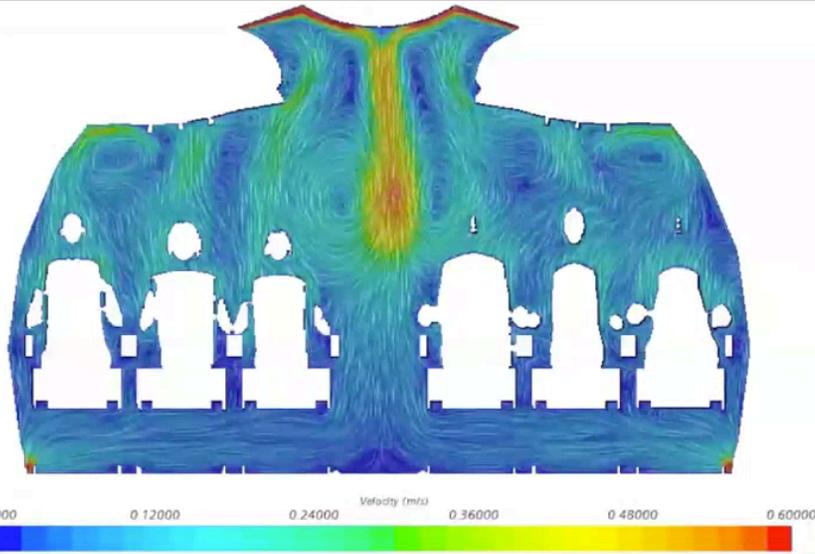
Airflow in confined spaces simulated for passenger comfort or ventilation system design



Cabin air flow

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URANS run for 2-4 mins

Humidity 10% in cabin

Human models from Siemens Jack software

Temperature set for head/body

Thermal comfort modeling

Respiration from nose

Gaspers on/off

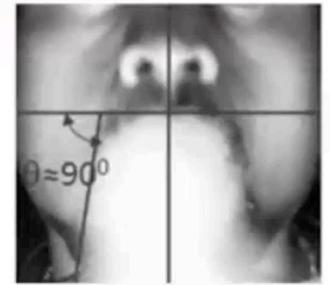
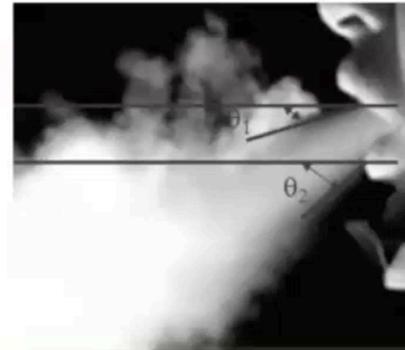
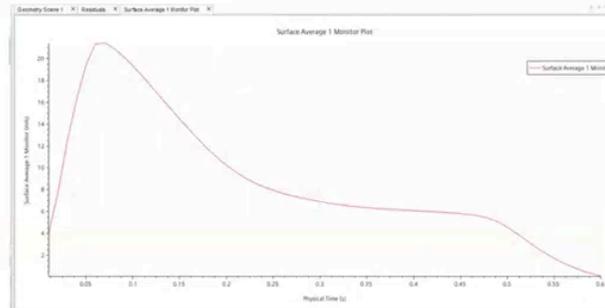
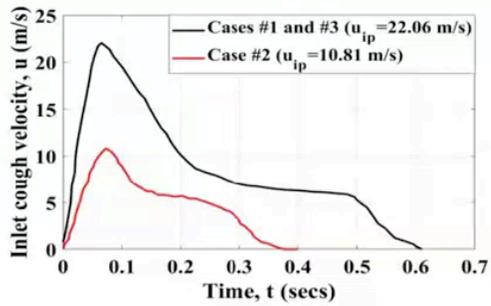
Mitigation efforts (barriers, shields)

Cough jet profile

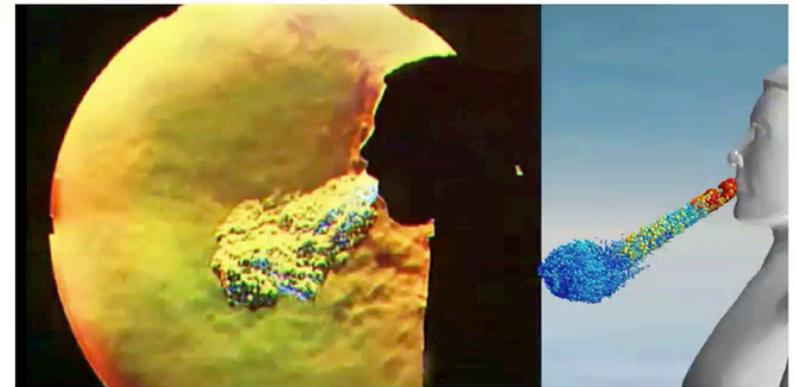


Test

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Model the time-dependent cough jet velocity
 Multicomponent – Air (94%) + water vapor (6%)
 Non-evaporative 6%
 Representative angle
 Averaged mouth opening area = 4 sq. cm



Droplet distribution, tracking and evaporation

Simcenter STAR-CCM+

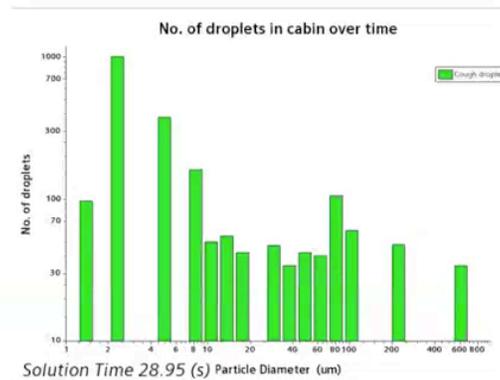
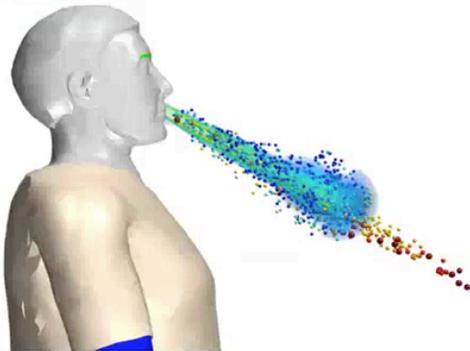


Table 3.2: Droplet size distribution (reproduced from Duguid (1946)).

Diameter class, µm	Number of droplets (N)	Mass flow rate, kg/sec
3	76	1.07442e-9
6	1041	1.17621e-7
12	386	3.43816e-7
20	127	5.27788e-7
28	47	5.28726e-7
36	45	1.07488e-6
45	38	1.81309e-6
62.5	38	4.85761e-6
87.5	27	9.12003e-6
112.5	32	2.38565e-5
137.5	30	4.08346e-5
175	83	2.35718e-4
225	47	2.74349e-4
375	40	1.10447e-3
750	27	5.74322e-3
Total	2084	7.44083e-3

No. of droplets in a cough = 2000 – 10,000
 Diameter range = 0.1 – 750 micron
 Injection time = 0.042 – 0.136 sec
 Drag, gravity, thermophoresis, Stokes

Evaporation, inertia, gravity and drag
 Humidity in cabin (10%) and cough jet (80-90%)
 Droplet tracking – 2 – 4 minutes

Single cough vs statistical (Empty room)

What you see is not what happens

128 compute cores
Under 1 day for airflow + cough
computation

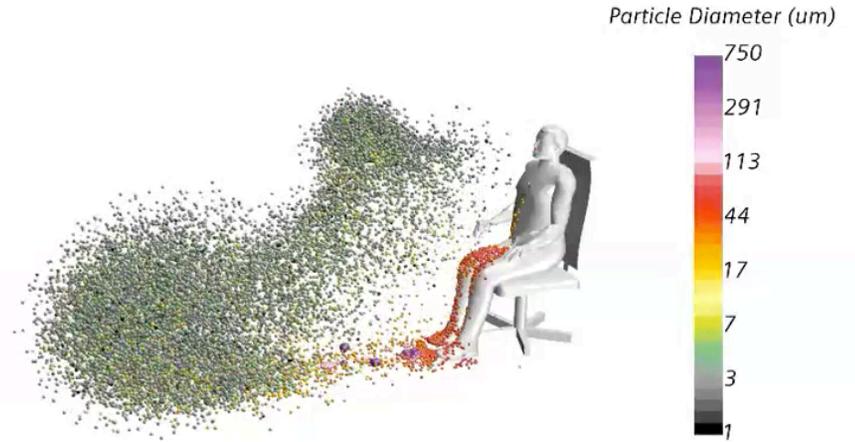
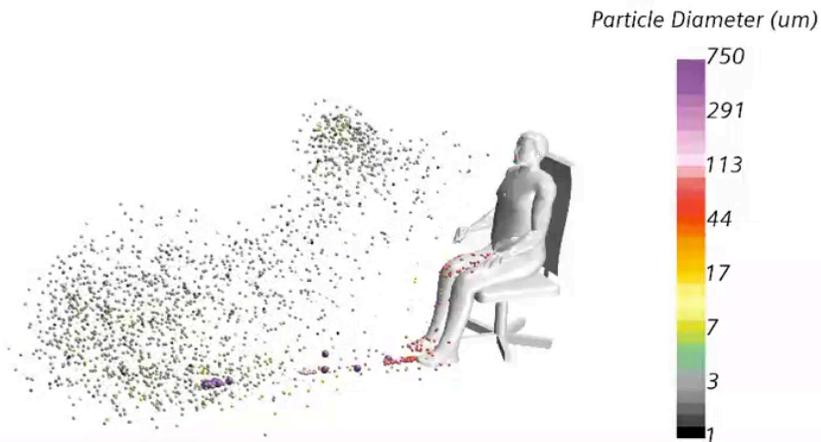


Simcenter STAR-CCM+

Solution Time 54.9 (s)

Simcenter STAR-CCM+

Solution Time 54.25 (s)



Modeling exact no. of particles (2084)
Realistic representation

Parcel approach usually used for large no. of droplets
Ex: 1e6 droplets represented by 1e3 parcels

Reducing droplet transmission

Masks – our greatest ally



Source: New York Times

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Mask Type	Standards	Filtration Effectiveness		
 Single-Use Face Mask	China: YY/T0969	3.0 Microns: ≥95% 0.1 Microns: ❌		
		<small>China: YY/T0969 USA: ASTM F2100 Europe: EN 14683</small>		
 Surgical Mask	China: YY 0469	3.0 Microns: ≥95% 0.1 Microns: ≥30%		
	USA: ASTM F2100	Level 1	Level 2	Level 3
		3.0 Microns: ≥95% 0.1 Microns: ≥95%	3.0 Microns: ≥98% 0.1 Microns: ≥98%	3.0 Microns: ≥98% 0.1 Microns: ≥98%
	Europe: EN 14683	Type I	Type II	Type III
3.0 Microns: ≥95% 0.1 Microns: ❌		3.0 Microns: ≥98% 0.1 Microns: ❌	3.0 Microns: ≥98% 0.1 Microns: ❌	
 Respirator Mask	USA: NIOSH (42 CFR 84)	N95 / KN95	N99 / KN99	N100 / KN100
	China: GB2626	0.3 Microns: ≥95%	0.3 Microns: ≥99%	0.3 Microns: ≥99.97%
	Europe: EN 149:2001	FFP1	FFP2	FFP3
		0.3 Microns: ≥80%	0.3 Microns: ≥94%	0.3 Microns: 99%

3.0 Microns: Bacteria Filtration Efficiency standard (BFE).

0.1 Microns: Particle Filtration Efficiency standard (PFE).

0.3 Microns: Used to represent the most-penetrating particle size (MPPS), which is the most difficult size particle to capture.

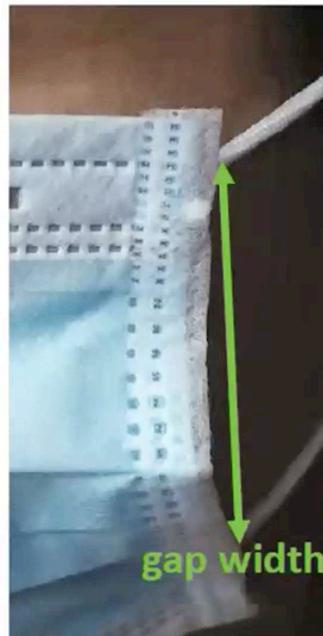
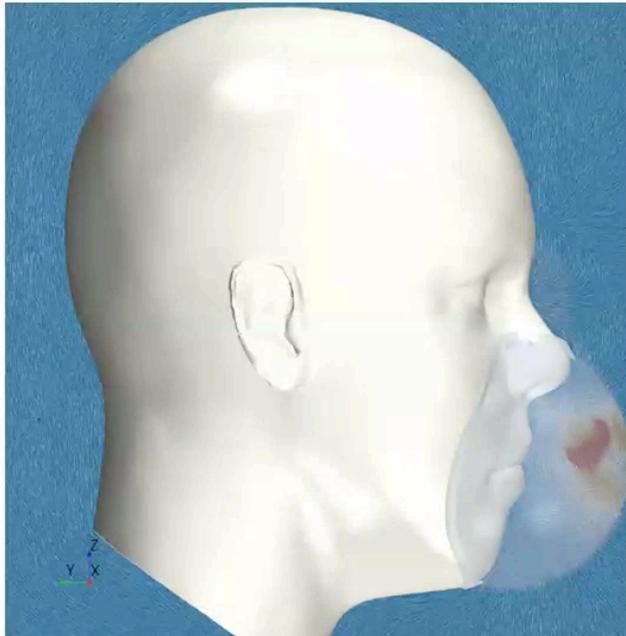
❌: No requirements.

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Modeling a mask Challenges

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Diameter	Efficiency
4.00E-07	0.4
8.50E-07	0.5
9.50E-07	0.6
1.50E-06	0.9
2.50E-06	0.95
3.50E-06	0.95
4.50E-06	0.95
7.50E-06	0.98
1.25E-05	0.99
1.75E-05	0.99
2.25E-05	1
1.00E-03	1

Analytical and numerical investigation of the airflow in face masks used for protection against COVID-19 virus – implications for mask design and usage

R. Perić^{1†} and M. Perić²

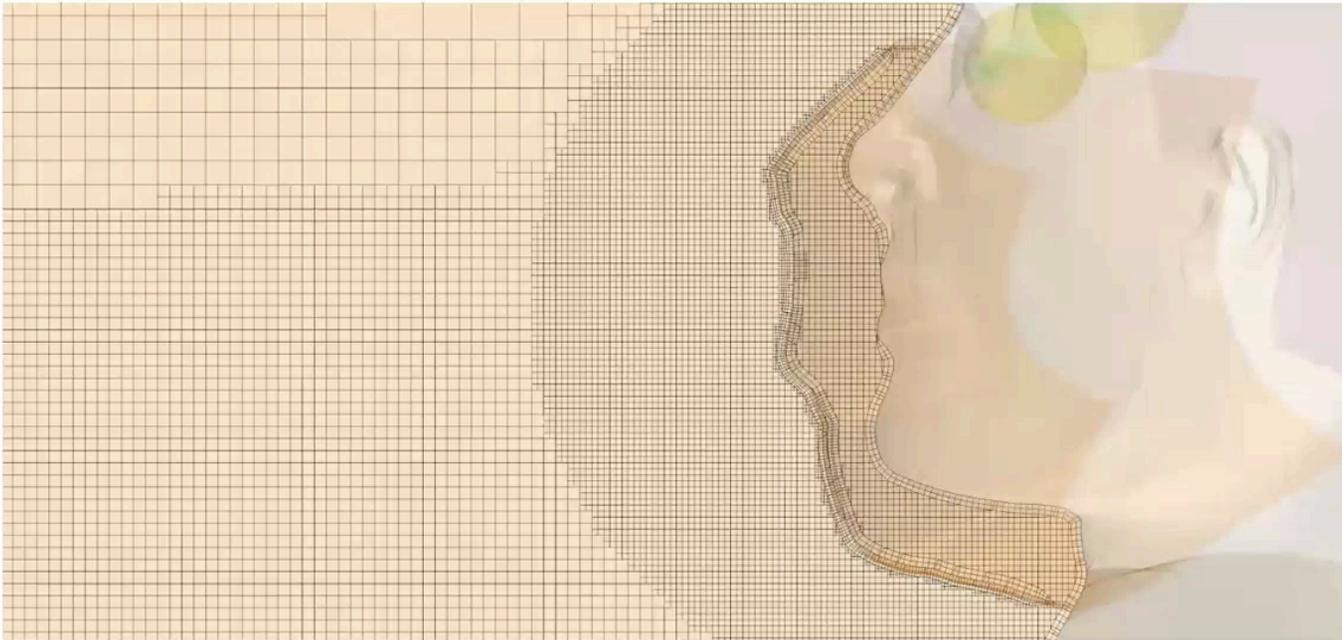
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Modeling a mask Challenges

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7.50E-06	0.98
1.25E-05	0.99
1.75E-05	0.99
2.25E-05	1
1.00E-03	1

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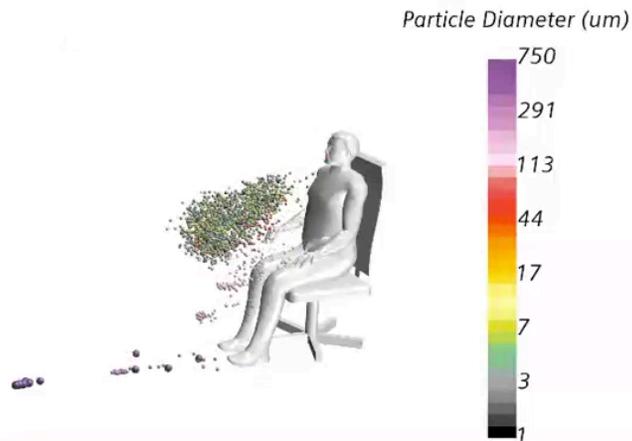
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Simulating a single cough (Empty room) No mask vs mask



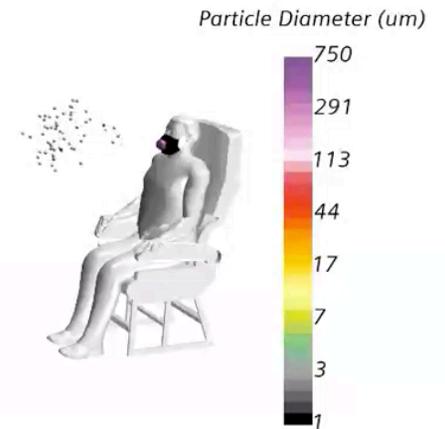
Simcenter STAR-CCM+

Solution Time 0.855 (s)



Simcenter STAR-CCM+

Solution Time 0.9 (s)



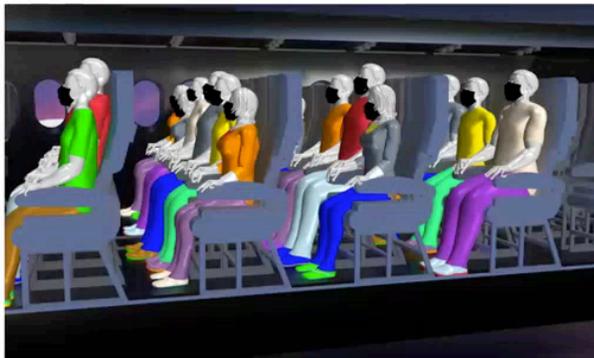
Coughing without a mask
Realistic representation of a single cough

Mask modeled as a baffle interface
Gaps on the sides, top and bottom modeled
Filtration efficiency assumed from triple layer masks
viscous porous resistance, $C_m = 2000 \text{ m/s } u$

Airbus / Siemens

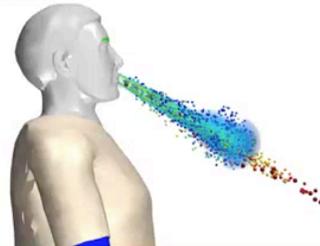
CFD simulation of cough droplet propagation in aircraft cabin

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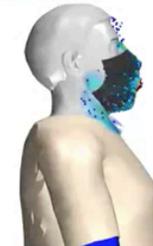
Understanding transport of particles from a human cough in aircraft cabin

Simcenter STAR-CCM+



Simulation without a mask

Simcenter STAR-CCM+



Simulation with a mask

- Simulation of cough in aircraft cabin
- With/without a mask
- Asynchronous breathing included
- Risk assessment indicators in cabin
- Validated aerothermal cabin airflow used

- Leaving middle seat open doesn't change risk factor
- With mask, less than 1% particles remain airborne in less than 2 minutes

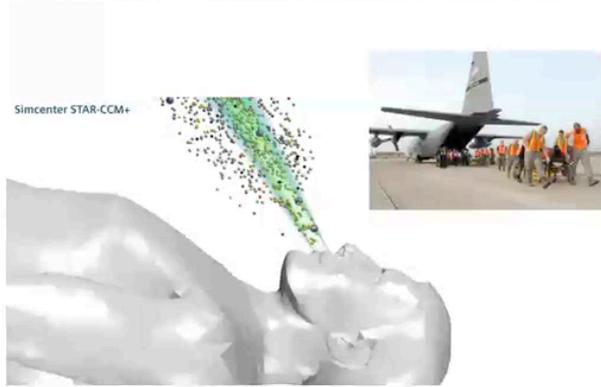
KPIs:

- Counting inhaled particles per passenger
- Particle size characterization
- Particles in breathing zone
- Time to reach <1% airborne particles

Courtesy: <https://www.plm.automation.siemens.com/global/en/webinar/high-fidelity-cough-simulation/78865>

Medevac Cabin Analysis – UES/USAF

Identify bioaerosol contamination to safely airlift COVID-19 patients

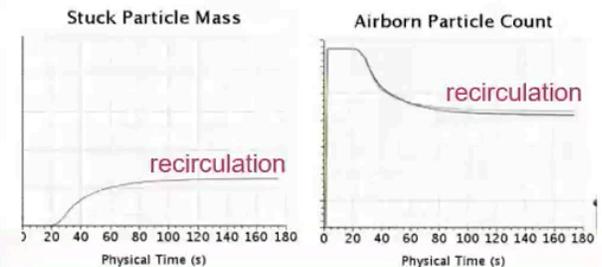


www.acc.af.mil/News

Droplets from sick passenger injected and tracked throughout the aircraft cabin using Simcenter STAR-CCM+ multi-phase functionality



www.acc.af.mil/News



Particle incident mass and resonance times predicted

- C-130 aircraft scenario
- 200 CPUs in a few days
- Transient multi-phase cabin with +100,000 Lagrangian particles
- Solve quickly using High Performance Computing cluster
- Infected passengers on beds
- [Simcenter Engineering Services](#)

Simulation tracks particles in time and predicts where different size particles land

- Output aides in the design of the cabin ventilation & aircrew safety procedures
- Helped identify contamination hotspots for disinfection purposes

“The airflow study enables mission planners to understand and visualize how the air and any biological contaminants will move inside the cargo aircraft and best mitigate the risks. This data makes in-patient transfer and overall Air Force personnel transport safer for all involved”

UES

<https://www.plm.automation.siemens.com/global/en/our-story/customers/ues-simcenter/90375/>

Heraeus Noblelight

Designing a 99.99% efficient UV-C purifier with CFD



Soluva UV-C air purifier designed with CFD simulation



- New device designed and validated with simulation
- Experiments proved 99.99% purification efficiency
- Droplet simulation with Simcenter STAR-CCM+ to assess device performance
- First device already fitted in regional bus

"It is much easier to first model a product in the virtual world than to physically assemble it directly. Thanks to the precise simulation, we saved many production steps and immediately knew what to look out for"

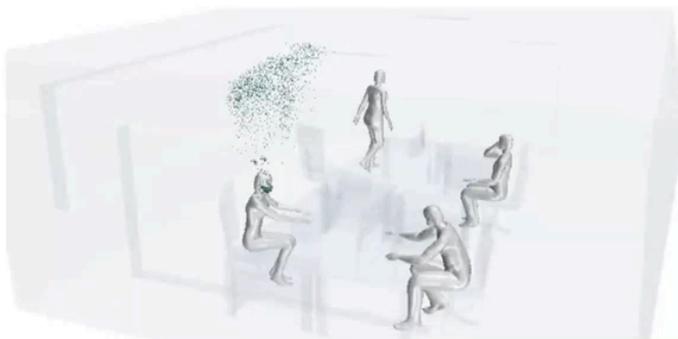
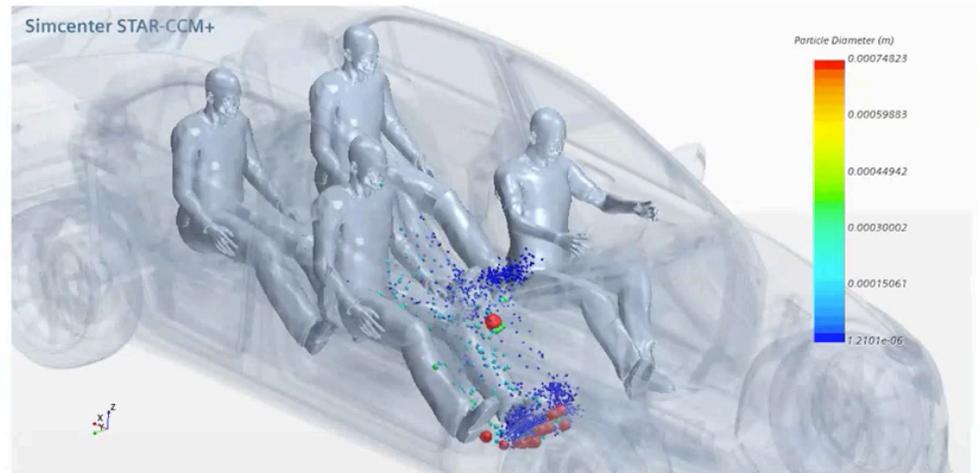
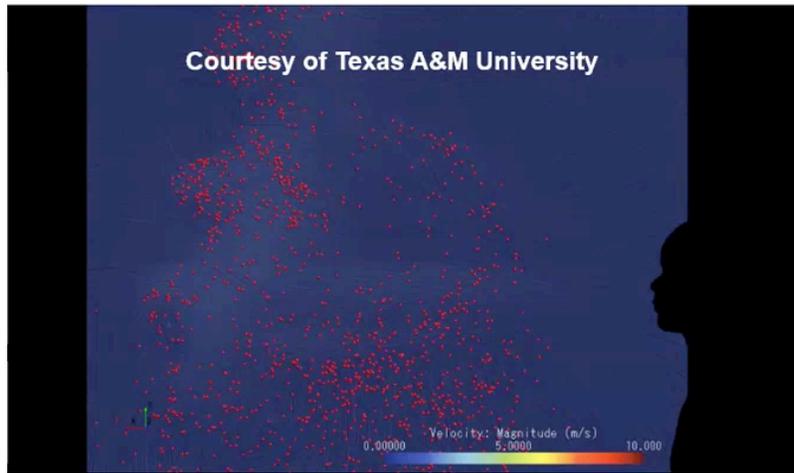
- Dr. Larisa von Riewel, CAE and simulation expert

Courtesy: https://www.heraeus.com/en/group/innovation/press_and_news_1/2020_4/virtual_simulation_air_disinfection.html

Cough/sneeze in other spaces

Industrial use cases

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Keys to modeling a cough in an airplane accurately

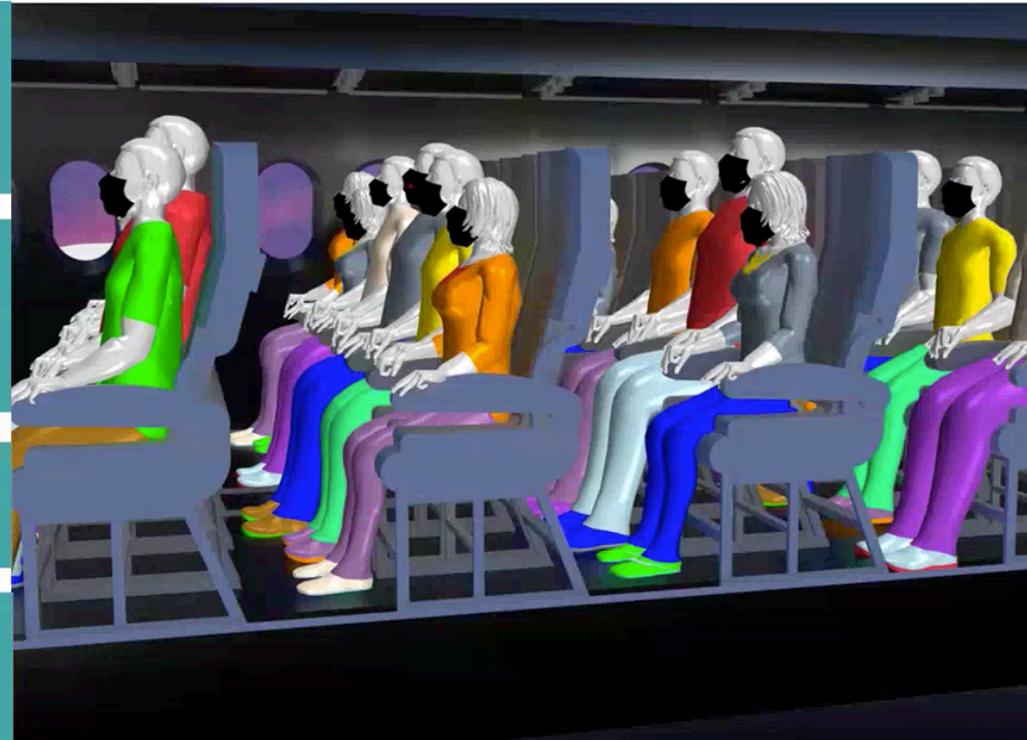
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Diligent modeling to include as many relevant variables

Multiphysics CFD simulation approach to accurately model the scenarios

Proper representation of the cabin environment

Right approach to droplet tracking



How can we help?

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